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SOME ECONOMIC ASPECTS OF AIR POLLUTION CONTROL WITH SPECIAL REFERENCE TO POLK COUNTY, FLORIDA

Thomas D. Crocker

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by

THOMAS D. CROCKER

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January, 1968

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Finally, the responsibility for typing and putting together this final report fell to Mrs. Lois Grebe. Her competence is fully and positively demonstrated in the next three hundred odd pages.

In accordance with the usual disclaimer, any errors of fact, concept, and/or technique remain the author's unique responsibility.

THOMAS D. CROCKER

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CHAPTER 1

INTRODUCTION

> I am looking from my office, where a stingy
> Ray of sunlight struggles feebly twixt the
> buildings tall,
>
> And the fetid air and gritty of the dusty,
> dirty city, Through the open window floating,
> spreads its foulness over all.

1. STATEMENT OF THE PROBLEM

If one is to believe the press notices, there is little doubt that the modern citizen, whether he be an urban dweller or a rural dweller, would find more than a little relevance in the above verse. Some popular commentaries appear to be attempting to give their readers the impression that scientists will soon hotly be discussing the merits of pumping air from caskets about to be buried in the ground relative to the desirability of creating a near vacuum in all spacecraft before the craft have even left the launching pad. Images of people wearing gas masks or warnings of the imminent abandonment of whole cities and sections of countryside do serve to arouse the interest of the public. But they contribute little to the objective amelioration of the supposed air pollution problem.

The air pollution problem is clearly one of those cases of market failure, which, though long sensed, if not made analytically explicit by noneconomists, has only recently been felt by economists themselves to be deserving of analysis.[1] The forecasts of atmospheric pollution increasing at something closely approximating a Malthusian rate and the warnings about so-called "shortages" of clean air which abound in the mass communications media imply that the present system of controlling atmospheric pollution is not performing as well as would a modified system. In other words, noneconomists and lately even economists feel that the present means of allocating the air resource among uses and users is not performing as it should perform and, more important, as it could perform. More precisely, the view is that the relevant variables have not been varying as they should and could. One might reasonably infer that those asserting the existence of an atmospheric pollution problem would have knowledge of the means by which these variables might be made to change and the manner in which they have changed under various sets of circumstances in the past. However, although there is consensus about the existence of some sort of air pollution problem there is a profound absence of agreement as to its nature, its magnitude, and what, if anything, should be done about it.

---

[1] As early as 1306, English courts were enforcing statutes designed to curb the fouling of the air by the production processes of candlestick makers. At the same time, efforts were being made in London to limit the burning of soft coal. John Evelyn, in his well-known pamphlet, _Fumi-Fugium; or The Inconvenience of the Aer, and Smoake of London Dissipated_, published in 1661, reports that some offenders were even executed. I am indebted to Paul G. Neimann for these examples.

Any view of the means by which any air pollution problem is to be ameliorated will be colored by and must begin from a premise about the place which the use of the air's waste disposal abilities holds in man's desired scheme of things. In the materials dealing with air pollution that most people are familiar with, a more or less quasi-philosophical and macrocosmic view of the problem is taken: the economic aspect of man and the biological aspect of man are considered to be competitive. That is, an increase in the degree to which one holds sway must necessarily reduce the interval over which the other is operative. Supposedly, there exists an entirely separate and readily identifiable part of each and every individual the essence of which is economic while there exists another part the essence of which is biological: the essence of any air pollution problem is to be found in a conflict between homo oeconomicus and homo sapiens. Only the former or economic part emits pollutant materials into the atmosphere while the latter or biological part attaches a high value--even an infinite value--to something called "clean" air. The basic thesis is that in the modern industrial world economic man has acquired too much power at the expense of biological man and that this is the root cause of the air pollution and other problems of environmental quality with which we are faced. From this thesis there easily follows the assertion that in order to maintain some sort of unspecified balance between the two, it becomes necessary to control the rampant nature of economic man. Or, less daintily, we are presented with the rather crude and ugly scene of economic man greedily tearing off and consuming pieces of his own flesh, thereby defeating the ultimate purpose the economic part of man's nature is expected to serve: biological survival.[2] The scene resulting from this approach includes supposedly knowledgeable authorities feeling no qualms about making declarations to the effect that "clean" air is worth paying for "whatever the costs in time, money and effort."[3]

---

[2] Examples of this approach are not at all difficult to find. The Air Conservation Commission of the American Association for the Advancement of Science states that "to tamper with the processes which create air pollution is to tamper with human civilization, but to ignore it is to ignore a threat to human survival." See Air Conservation, (Wash., D.C.: American Association for the Advancement of Science, 1965), p. 3. In a similar vein, the Environmental Pollution Panel of the President's Science Advisory Committee asserts that "the production of pollutants and an increasing need for pollution management are an inevitable concomitant of a technological society with a high standard of living. Pollution problems will increase in importance as our technology and standard of living continue to grow." See Restoring the Quality of Our Environment, (The White House, Nov., 1965) p.1.

[3] Leslie A. Chambers, "Classification and Extent of Air Pollution Problems," in Arthur C. Stern (ed.), Air Pollution, Vol. 1 (New York: Academic Press, 1962) p. 21. If carried to its logical and quite

The specific policy proposals following from this competition thesis are rarely heavily endowed with clarity. The constant emphasis upon the association between increases in the standard of living (real per capita incomes?) and increases in the physical quantities of pollutant materials placed in the environment might be taken to mean in terms of policy that increases in the standard of living should be allowed insofar as there are commensurate increases in the environment's absolute physical capacity to handle increased pollution loads. Or, if biological survival is taken to be the end, then air pollution might be serving a positive purpose by ensuring that existing members of the species with relatively weak respiratory systems do not pass this trait on to their descendents. On the other hand, simple charity and brotherhood as well as the interests of society in preserving those members of the species with mixes of those traits considered at the moment to be highly desirable might imply the avoidance of any and all acts tending to reduce the mathematical expectation of any single homo sapien member's chances of survival. Other possible policy interpretations come easily to mind.

It may or may not be true that higher levels of real per capita income and biological survival are incompatible. Certainly, whatever the concept of biological survival being espoused, no substantive evidence exists. Nevertheless, it is clear that though increases in real per capita incomes and levels of atmospheric pollution loadings have perhaps historically often tended to be associated, this does not mean

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ridiculous conclusion, the statement implies that clean air has infinite value while everything else in the world to which it is generally thought men attach a positive value is to be treated as having a zero value.

that they are directly related. In fact, the economist's view of man's nature would make it appear that actual pollution loadings and real per capita incomes are inversely related, even though potential pollution loadings and real per capita incomes are probably directly related.[4]

In the economist's context, the most basic consideration is the old and probably somewhat tiresome caveat that human wants are for all practical purposes unlimited while the means with which to satisfy these wants are limited. In fact, as long as there is at least one person in the world who does not have everything he wants, including time, the problems raised by economic scarcity will continue to be present. The economic issue is then one of deciding how best to satisfy these wants given the obviously limited availability of means. The issue is therefore fundamentally one of choice: not choice in the sense of an infinite set of either/or alternatives but choice in the sense of an optimum degree of thirst-fulfillment for a whole ordered hierarchy of wants.[5]

Few would deny that the highest place in this hierarchy belongs to the basic and fundamental biological wants: the subsistence needs for food, clothing, and shelter. Those needs and objectives of economic activity having the highest priority for nearly every individual and every society are the provision of the means for the satisfaction of these elementary wants in a manner which will best ensure the preservation of those attributes of the human species existing individuals consider to be highly desirable. As wants of the highest priority are satisfied, attempts are then made to satisfy the wants initially relegated to the next highest priority until such time as those wants having the lowest priority, given the available means, are satisfied. But this does not mean that all wants to which the highest priority is initially attached are completely satiated, for as the individual or the collection of individuals making up the society partially fulfill their wants in the highest priorities, the satisfaction to be obtained from wants in the lower priorities will increase in relative value. That is, at some point in the fulfillment of those wants to which the individual initially attaches the highest priority, the fulfillment of those wants in all lower priorities will take on greater significance; or, as needs are partially fulfilled, the hierarchy of wants will change. That need to which the highest priority was initially given will after it has been partially satisfied drop down to a lower position in the ordering and another want formerly of a lower order will now become of the highest order.

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[4] By potential pollution loading is meant that pollutant load which would be placed in the atmosphere in circumstances where the air's waste disposal abilities can be treated as a free good. Basically, for any given state of technology, the concept involves that set of circumstances in which it never is worthwhile for any single emitter to give explicit attention to the engineering efficiency with which certain physical and/or chemical components of the inputs associated with the emitter's production processes are recovered and/or retained.

[5] Alfred Marshall, Principles of Economics, 8th Ed., (London: MacMillan and Co. Ltd., 1950), pp. 86-91.

Given the validity of the preceding statements, the basis upon which most choices are made is that attribute of an alternative having a lower priority in an initial or primary ordering. Or, to put the matter in a slightly different way, for any pair of alternatives from which one can choose, with each alternative having several different attributes or features, that attribute or feature upon which choice will be based is that attribute having a lesser relevance in a primary ordering. Thus if I've already had my fill of extravagant foods, when

I must choose between and among restaurants I will select that restaurant having its waitresses in the briefest costumes or that restaurant which is most pleasantly decorated. Or, if I must choose between two otherwise equally satisfactory homesites, I will select that site which is not downwind from a smoky factory. However, if the choice is one of starving in an idyllic setting or having wholesome food and adequate shelter while living near the smoky factory in which I earn the money to buy this food and build this shelter, I will choose to live near the factory. Thus over some set of orderings of my wants I will always select that set of alternatives which best satisfies my basic so-called biological needs; but after some positive degree of satisfaction of these needs has been achieved and is being maintained, I will then reorder my wants so that cleaner air receives higher priority than does additional food, clothing and shelter. Only after I have begun to feed my body will I feed my soul; and soul feeding, as is cleaner air, is a superior economic good: that is, a good which varies directly with real income, or with the extent to which I have been able and expect to continue to be able to satisfy those needs having a higher priority in my primary orderings.

Some rather impressionistic evidence is available to support the contention that an absence of air pollution is a superior good. Consider the following examples which, though they involve the usual public goods or free rider problem often associated with interviewing techniques,[6] at least do not provide any grounds for rejecting the superior good hypothesis.

---

[6] Cf. P. A. Samuelson, "The Pure Theory of Public Expenditure," and "Diagrammatic Exposition of a Theory of Public Expenditure," Review of Economics and Statistics, 36 (November, 1954), pp. 387-89, and 37 (November, 1955) pp. 350-356. If the interviewee will not be subject to air pollution controls during the course of his normal activities, if he actually desires cleaner air, and if he is given reason to think that the intensity of desire for clean air expressed

First, a sociological study conducted by the U.S. Public Health Service in Clarkston, Washington, a city near which a kraft pulp mill with its associated odor, dust and fume problems is located, found that forty-four per cent of the local managers, proprietors, and professional people--a group one would expect to have a greater frequency of relatively high incomes--were "aware" of an air pollution problem and were seriously "concerned" about its effect upon their health and their real properties. However, only thirty-two per cent of the clerical and skilled laborers, and only nineteen per cent of the sem-skilled and unskilled workers expressed a similar awareness and concern.[7]

Whatever the number of sociological studies which might be marshalled for the support of the public good hypothesis, this hypothesis

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in his answers will be directly related to the degree of clean air ultimately provided, he will have an incentive to overstate the intensity of his desire. The reason for this is that unless he must bear some visible direct or indirect burden of the control costs, his answer or rather the results of his answer are to him essentially costless, i.e., he can appropriate the benefits flowing from the provision of cleaner air without having to compensate anyone for the costs of such provision.

[7] Nahum Z. Medelia, et. al., Community Perception of Air Quality: An Opinion Survey in Clarkston, Washington, U. S. Public Health Service, Publication #999-AP-10 (Cincinnati, Ohio: Robert A. Taft Sanitary Engineering Center, June 1965) pp. 45-55. Other sociological studies appear to have had similar findings. Cf. W. S. Smith, et. al.,"The Public Reaction to Air Pollution in Nashville, Tennessee," Air Pollution Control Association, Journal, 14 (October, 1964), pp. 418-423) and I. DeGroot, et. al., "People and Air Pollution: A Study of Attitudes in Buffalo, New York," Air Pollution Control Association, Journal, Part 1 of 11, 16 (May 1966), pp. 254-57.

is perhaps most dramatically supported by the following statement made in response to a mail questionnaire survey concerning air pollution's health effects in Polk County, Florida and carried out by the Florida State Board of Health. The rather ambivalent statement was made by a person who had apparently signed a privately sponsored petition intended to protest that local air pollution problem thought to be caused by the emission of gaseous and particulate fluorides from phosphatic fertilizer manufacturing processes.

> I am sorry about this matter. I was misinformed. My husband has worked for one of the phosphate plants for 21 years. The mine has been our bread and butter. We have not been harmed in any way mentioned above. Thank you.
>
> P. S. The dust does get pretty bad.[8]

Finally, for whatever it is worth, one might note the assertion of a recent national television network "news special" that the City of Pittsburgh and its large steel firms did not reduce their air pollution problems because of any real concern for existing residents and workers but only because the firms could not otherwise convince would-be key executives and technicians and their wives to come to live in the city and/or its environs.[9] Evidently the workers and residents, if provided the opportunity to express their views would have repeated the still heard rhetoric about smoky factory chimneys and relative worker prosperity always being associated and perhaps even causally related.

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[8] Florida Air Pollution Control Commission, "Addendum No. 3" Florida Air Pollution Control Commission: Minutes, September 16, 1966 (Jacksonville: Florida State Board of Health, 1966) p. 2.

[9] The writer is unable to remember the exact date on which the program was presented. However, it was presented on the NBC television network sometime in the last three months of 1966.

From the preceding it would appear that, if anything, increases in per capita incomes would intensify man's desire for cleaner air. Conversely, a general reduction in per capita incomes would tend to reduce man's aversion to "dirty" air. The higher are per capita incomes, the more in physical terms and in value terms will man be willing to forego in order to achieve and to maintain a given state of atmospheric cleanliness. Furthermore, once a fairly high level of real per capita income is achieved and can reasonably be expected to be maintained, it is likely that the proportionate increase in the demand for cleaner air resulting from further increases in real per capita incomes will be greater than the proportionate increase in incomes. In short, if the state of the air's cleanliness in any locale is to be made responsive to the wishes of the citizenry, then a higher state of cleanliness can be attained when the citizenry's real per capita incomes are relatively high than when they are relatively low. Even though potential air pollutant loadings might be less with low real per capita income levels, actual air pollutant loadings per unit of potential loadings will be higher because relatively clean air will fall back to a lower position in the citizenry's priority orderings. The ordering of wants, rather than remaining constant as the advocates of the competition thesis seem to assume, shifts with changes in real per capita incomes. Intrinsically therefore--stripped, that is, of all extraneous and complicating factors--higher real per capita incomes and cleaner air tend to be complementary rather than competitive.[10]

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[10] The complicating factors, many of which will be examined in Chapter II, are mainly due to physical and temporal indivisibilities.

Though there appear to exist strong grounds for the point of view that cleaner air is a superior economic good, this point in and of itself, except for questions of distributive equity, is of relatively slight economic interest.[11] Before one can deal adequately with questions of distributive equity, it is necessary to have something more than a superficial understanding of the microeconomic nature of the air pollution problem, its economic magnitude, and, given the nature and magnitude, the corrective measures which might be taken in order to maximize the economic returns to be derived from the air resource. If and only if one knows what spatial and temporal configuration of rights to the use of the air resource will in any given locale serve to approximate maximization of the resource's net economic returns can one know what cost in terms of allocative efficiency is required in order to achieve and to maintain whatever conception of distributive equity happens to have the greatest number of politically influential adherents.

Certainly, the greatest disservice that much of the furor in both the mass media and the technical publications is causing is that it has a pronounced tendency to present public issues involving air pollution in terms that encourage response at the expense of understanding.

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[11] One wonders, nevertheless, just how much of the emphasis on and concern about pollution problems would exist apart from the contemporary middle and upper class odor and dirt phobia, along with the advertising industry's emphasis upon odor and dirt as nonstatus symbols. Some court cases exist in which a large firm has actually been shut down and numerous workers thrown out of work in order to stop pollutant fumigations from harming a single or a small number of already well-to-do landowners. See, for example, Hulbert v. California Portland Cement Co., 161 Calif. 239 (1911). However, many courts in the process of "balancing the equities" do attempt to weigh worker and public interests against those of the supposedly damaged property owner. See, for example, Storey v. Central Hide Rendering Plant, 148 Tex. 109, 226 S. W. 2nd 615 (1950); and Arvidson v. Reynolds Metals, 125 F. Supp. 481 (1954).

This misunderstanding is due primarily to the fact that the advocates of different particular points of view start from disparate value premises about questions of distributive equity and therefore cannot hope to communicate or even to commiserate with each other in anything other than rather mysterious and metaphysical language.[12] In addition, it is highly unlikely that the alternatives are quite as stark as the more excitable proponents of many of these views would have us believe. In any case, the ability of economic analysis to reduce the alternatives which differing specialized vocabularies espouse to a common measure of gain and loss must at least serve to facilitate, if not make certain, well-reasoned judgments about the relative efficacies of these alternatives. Certainly there are voluminous writings dealing with the physical, chemical, biological, and even the legal aspects of air pollution, but there is little if anything dealing with the problem's economic aspects that does not take as a starting premise one or more of the views peculiar to specialized vocabularies. Undoubtedly, this failure to employ economics adequately as a means of evaluating control measures is due to both the analytical difficulties involved in conceptualizing the problem, and even if conceptualized, the task of measuring and testing the relations implied by these conceptual constructs. Nevertheless, emphasis cannot remain solely upon discovering what is scientifically and/or legally possible. Some attention must also be devoted to that which is economically possible.

---

[12] Consider the previously mentioned statement that "to tamper with the processes which create air pollution is to tamper with human civilization, but to ignore it is to ignore a threat to human survival." Although the statement might well be true, it and others like it certainly cannot offer much help in making the decision as to how much civilization is worth how much survival. See Air Conservation Commission, op. cit.

The lack of attention given to the economic aspects of the air pollution problem is generally reflected in two ways: the ridiculousness of the measurement techniques underlying most estimates of air pollution damages and the rather questionable economic validity of many of the proposals which have been advanced for the control of air pollution. First, consider some of the more common means by which damage estimates are arrived at. That figure which is most often quoted--in fact, it is practically impossible to read or to listen to any utterance about air pollution by a noneconomist in which this figure is not referred to--is eleven billion dollars annually in national damages for the United States. According to a recent paper by Michelson and Tourin,[13] this eleven billion dollar figure was obtained by taking 1913 smoke damage data collected by the Mellon Institute in Pittsburgh, Pennsylvania, dividing this total damage figure by the 1913 Pittsburgh population and thus obtaining a 1913 Pittsburgh per capita damage figure of twenty dollars. This figure of twenty dollars per capita was then adjusted by a 1959 commodity price index so as to obtain a 1959 per capita damage figure of sixty dollars. Finally, this sixty dollar figure when multiplied by the 1959 United States population magically provides the desired eleven billion dollar answer. On a more disaggregated level, a St. Louis, Missouri air pollution study group estimated air pollution damages to the St. Louis Metropolitan area by multiplying the aforementioned sixty dollars by the St. Louis urban area population.[14]

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[13] Irving Michelson, Boris Tourin, "Comparative Method for Studying Costs of Air Pollution," Public Health Reports, 81(June 1966) p. 505.

[14] Allen V. Kneese, "How Much is Air Pollution Costing Us?" (paper read at the National Conference on Air Pollution, Washington D.C., December 13, 1966), p. 2. (Mimeographed.)

The preceding examples are primarily concerned with air pollution damages in urban areas; yet similar types of estimates are often made for rural and agricultural areas. Even though most literature in which such estimates appear contains quite highly detailed and technical discussions of what appear to be damage symptoms, most dollar damage estimates are obtained by inquiring of farmers in the affected area the difference between their yields with and without pollution. A multiplication of their answers by the commodity's going market price gives a number stated in terms of dollars that is presumed to be equivalent to economic damages.[15]

Though the above recitation of the manner in which air pollution damages have typically been determined provide few if any grounds for confidence in the resultant magnitudes, one can easily and readily sympathize with the desire to have available--if only as a basis for discussion and criticism--some sort of quantitative material. To be sure, as the basic necessities play a smaller and smaller role in the determination of economic welfare, the economic implications of production and consumption become harder and harder to measure. Part of this increasing difficulty in measurement is perhaps due to the possibility that wants which are a lower priority in less prosperous times are not readily signaled by the usual pricing devices even when these wants take on the highest priority. Another reason for this measurement difficulty is perhaps the lack of conceptual constructs available to the economist which would enable him to make fairly general predictions about the results of the interdependent production and consumption decisions arising from congestion. Or perhaps the economist has better felt his talents devoted to maintaining international liquidity in gold or to explaining the corn-hog cycle. But whatever the reasons for the economist's neglect of this area, the neglect has brought about a situation in which the lawyer, the engineer, and the physical and natural scientist have felt themselves to be faced with a fundamentally insoluble problem--insoluble, that is, in terms of their own specialized vocabularies. For purposes of control, the conclusion has been that ritual and rigidity, in the form of insistences that every property owner has a right to clean air or that some long outmoded standard continue to be enforced, have been substituted for reason and flexibility.[16] Considerable grounds exist for the point of view that air pollution control programs as presently practiced and espoused have caused, and, unfortunately, are likely to continue to cause a state of affairs in which waste of the air resource, in the economic sense of the word, can be expected to take place.

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[15] Cf. A. Rodenhiser, Effects of Air Pollution on Crops and Livestock," National Conference on Air Pollution: Proceedings, U. S. Public Health Service, Publication No. 1022 (Washington D. C.: U.S. Government Printing Office, 1963) p. 177; and Bay Area Air Pollution Control District, Air Pollution in the Bay Area: Technical Report and Appraisals, (San Francisco: Board of Directors, Bay Area Air Pollution Control District, 1959), pp. 60-64.

The onus for the preceding state of affairs obviously does not attach to those who are directly harmed by air pollution. But neither does it attach to those who release the materials which cause the harm. Instead, the responsibility lies with a political and socio-economic system which has not yet discovered ways of making the relevant variables vary by anything other than strictly arbitrary means. The present state of affairs leaves both the individual and the society in a Pareto-worse situation: a situation in which everybody is likely to go up the stack together, landing only where the capriciousness of the winds of (ill) luck dictate. Opportunity for either private or public means of allocating the air resource over time and over space in accordance with an understanding of the criteria of economic efficiency has been almost totally lacking. The only methods yet employed and/or proposed have been fixed standards, mainly advanced by engineers and lawyers, and emitter charges, which for the most part have been advocated by a small group of economists.[17] But a common feature, at least in terms of degree if not in kind, of nearly all these proposals is that they fail to perceive adequately the economic nature of air pollution, its economic magnitudes, and the economic impact of various emitter and receptor responses to control measures. Unless a greater depth of understanding about these things is acquired, the present conflicts about atmospheric pollution are destined to continue unabated. The intent of this study is to contribute something, however small, to this understanding.

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[16] Professor Gordon Maskew Fair, an internationally recognized authority on the physical aspects of environmental quality problems, refers to many of these standards as "the artifacts of professional organizations."

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[17] That economist who has been most vocal and erudite about the emitter charge has been Allen V. Kneese of Resources for the Future, Inc. See his The Economics of Regional Water Quality Management, (Baltimore: The Johns Hopkins Press, 1964), 215 pp. That his ideas and views have had substantial impact upon higher advisory bodies of the Federal government is apparent in the following: The Environmental Pollution Panel, Restoring the Quality of Our Environment, (The White House: President's Science Advisory Committee, November 1965), pp. 17-18; and Committee on Pollution, Waste Management and Control, National Academy of Sciences - National Research Council. Publication 1400 (Washington, D. C.: Printing and Publishing Office, National Academy of Sciences, 1966) pp. 203-221.

II. STATEMENT OF OBJECTIVES

Ultimately, perhaps in the not too distant future, atmospheric pollution control programs will be able to attain and to sustain something approximating clean air. But, the victory, if one insists on calling it that, will not constitute proof that anything of value has been accomplished. Rather, it is possible and perhaps even probable all that will be shown is that one can achieve extremely rapid results if one is willing to force others to make sufficiently great sacrifices. Whether the results are warranted in terms of the results is basically a valuation question, and, as is well known, any problem of valuation is inseparable from the problem of allocation. In fact, valuation is a precondition for allocation, for the lack of a need for valuation would imply that the allocation problem did not exist. Thus if we solve or ameliorate the pricing or valuation problem, we solve the allocation problem, and similarly, if we solve the allocation problem, we simultaneously solve the pricing or valuation problem.[18]

Certainly the most dominant theme underlying the present furor about atmospheric pollution is uncertainty: uncertainty about the volumes and the types of pollutants which are emitted; uncertainty about what happens to these pollutants as they are transported through the atmosphere; uncertainty about how the pollutants are transported through the atmosphere; uncertainty about the effects of these pollutants upon receptors; and lastly, but most important, uncertainty about what to do with the air pollution problem--if it exists. Although this last element of uncertainty is probably intrinsically and analytically no more difficult than any of the other elements, it is this last element which nevertheless causes the greatest amount of controversy and which generates the greatest volume of words, both heated and non-heated. But this is to be expected, since the modes of thought involved in the analysis of the first four elements concern themselves solely with physical events, while the last element impinges directly upon those things which men value and therefore upon man himself. Ultimately, therefore, the last element reduces to a problem in valuation and allocation.

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[18] This symmetry is, of course, one of the touchstones of programming techniques, where it is generally called the dual.

When discussing any valuation and allocation problem it is necessary to keep in mind that there exist two seemingly rather separate and disparate levels of economic analysis. On the first level, the economic decision-maker can be viewed as an objective actor who voluntarily can and will seek to maximize the degree to which he satisfies his wants and needs. That is, the decision-maker is assumed to have a particular end in clear and unobstructed view and he is presumed to be fully cognizant of the connection between the benefits and costs accruing to the various alternative means he can employ to achieve this end and the end itself. At this level of analysis, the economist is concerned with the consequences of decision-makers acting in the aforementioned manner. Carried a step further, this first and really most basic level of analysis seeks to establish the conditions, both necessary and sufficient, for the decisions which are optimal for each and every individual decision-maker to result in a set of decisions which are optimal--in the sense of maximizing aggregate welfare, however defined--for the collection of all individual decision-makers.

At the second level of analysis, the question at issue is founded upon the premise that the individual decision-maker's attempts to maximize the degree to which he satisfies his wants and needs will not simultaneously serve to maximize the welfare of the collection of individual decision-makers. This absence of correspondence between individual and collective welfare occurs because the individual involuntarily cannot or because he voluntarily will not be operationally cognizant of the connection between certain of his means of achieving and maintaining his objectives and the achievement and maintenance of certain objectives thought desirable for and/or by the aggregate of individuals. At the first level of analysis, each decision-maker is viewed as an isolated unit in an impervious cell having contacts with other economic units only through a reasonably well-functioning market. If the market is not considered to be functioning well, then the job of the economist is to suggest how it might be restructured in order to function well, however well might be defined. This is the essence of the second level of analysis: to devise decision rules resulting in operations on the decisions of decision-makers which will enable each one of them to seek to maximize independently of every other decision-maker the degree to which he attains and sustains his objectives and which will simultaneously serve to maximize the degree to which the maximization of the collection of individual ends is achieved and maintained.

From the above, it is clear that there are two steps involved when searching for a way to solve or, more properly, to ameliorate a policy problem. First, the manner in which the necessary and sufficient conditions for simultaneous individual and collective maximization are being violated must be identified and specified,[19] and, second, ways must be found to negate the effects of these violations or to do away with the violations themselves so that the results of the analysis in the first step will be achieved. To take action on the second step without having a complete analytical understanding of the first step is to play at grabbing dreams from the air; but to complete the first step without ultimately attempting the second step is really not to complete the first step, for a simple elucidation of the conditions being violated offers few, if any, insights into the additional conditions which might be violated when devices are constructed for doing away with the initial set of violations.

The conditions in the first level of analysis for which one tries to discover whether or not violations have occurred are so well known and have been written about so extensively that it hardly seems worthwhile to repeat here that which is readily available elsewhere.[20]

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[19] Logically speaking, simultaneous individual and collective maximization is nonsense because it is mathematically impossible to maximize simultaneously two or more nonindependent functions. Some order of priority must therefore be attached to each function. The normative view generally taken in economics is that the individual attempts to maximize some objective function within the constraint imposed by whatever method of collective maximization is selected.

[20] A most complete and detailed presentation of these conditions is to be found in Robert E. Kuenne, The Theory of General Economic Equilibrium, (Princeton, New Jersey: Princeton University Press, 1963) 786 pp. In the context of statics and comparative statics, the following article is an excellent synthesis: Francis M. Bator, "The Simple Analytics of Welfare Maximization," The American Economic Review, 47 (March 1957) pp. 22-59. Although the dynamic conditions for economic efficiency are supposedly not nearly as well developed and systematized as are the static conditions, several economists, including Kenneth Arrow and Leonid Hurwicz, have made some progress in developing them. See, for example, their "Decentralization and Computation in Resource Allocation," in Ralph W. Pfouts, ed., Essays in Economics and Econometrics, (Chapel Hill: University of North Carolina Press, undated), pp. 34-104.

However, at the second level of analysis, the art's state--at least as it applies to the air pollution problem--is rather less well developed. Unless one insists under any and all circumstances that no foreign materials be placed into the atmosphere, he must admit that the atmosphere has two value dimensions: a life and property supporting ability and a waste disposal ability. Any attempt to suggest and to establish a means whereby these two values dimensions will be efficiently allocated over time and over space must proceed through three sequential steps, the first of which is the aforementioned specification and identification of the conditions being violated. Similarly, the third is the evaluation of the available means for negating the effects of or doing away with these violations. The second step, that step which must be taken in any policy application in order to go from the first to the third step, is the determination and confirmation of the nature and preferably the magnitude of the changes which must take place if a modified system is to function efficiently. In fact, with a reasonable knowledge of the possibilities involved in the first and third steps, one can acquire substantial knowledge as to which of the first and third steps' possibilities are actual by placing major emphasis upon the second step. Accordingly, the objective of this study is to estimate air pollution damages to agriculture in a small section of the United States, to infer from the pattern assumed by these estimates over time and from knowledge of the circumstances underlying this pattern the reasons why the pattern assumed the form it did, and to discuss the implications for and the possible impact of these reasons upon thinking concerning the economically viable structuring of atmospheric pollution control systems. More succinctly, by determining and by drawing inferences from the spatial and temporal pattern of apparent air pollution damages to the citurs and cattle industries of Polk County, Florida, an attempt is to be made to analyze what might commonly be some of the more important impediments to efficient management of the atmospheric resource and to identify the conditions under which significant institutional innovations might have to be made in order to improve management of this resource. In short, the objective is not to suggest a solution--if there is ever a solution to anything in a dynamic physical and intellectual world--to the Polk County or to the nation's air pollution problem, but only to point out that the empirical findings of this study provide some evidence that the commonly accepted and proposed means of control might provide few, if any, contributions to increasing the economic surplus generated by the use of the air resource.

The above point, it will be argued, appears to hold for that type of control measure (emission standards) generally advocated by local air pollution control administrators and authorities as well as for that type (charges) usually proposed by economists. In general, the local authority's difficulty is that it has been applying simple rules of thumb which set off, unrecognized by the authority and perhaps to its dismay, a long and complicated set of economic reactions; but the economist's difficulty has been that he assumes the involved economic nature of any air pollution problem requires a set of controls at least as involved as the problem itself. We shall argue that the economist is at least one-half right because the economic aspects of the problem are definitely not uncomplicated; but we shall simultaneously argue that the local authority's ideas on how to ameliorate the problem might, if properly employed, have greater economic validity than do the economist's.

III. DETAILED OBJECTIVES

The primary objective of this study is to contribute a few pieces to the development of a framework for the economic analysis and modification of air pollution problems.

A second objective involves the development of information dealing with the impact of atmospheric pollution on resource value and use, with particular emphasis upon land and its allocation between receptor and emitter uses.

A third objective is to evaluate within a relatively small, compact and homogeneous geographical area various measurement techniques which might be employed for the determination of atmospheric pollution damages.

A fourth and final objective is to develop some useful information about the local economy of Polk County, Florida, and to develop some information and constructs about the supposed Polk County air pollution problem which, it is hoped, will have applicability to both local and national air pollution policy.

IV. PLAN OF WORK

The following procedure will be followed in attempting to attain the aforementioned detailed objectives.

The next chapter, Chapter II, will discuss the economic meaning and nature of atmospheric pollution.

Chapter III provides information upon the economic backgrounds of Polk County's beef cattle, citrus, and phosphate fertilizer manufacturing industries. Included in the last part of this chapter is a short description of the manner in which potentially toxic particulate and gaseous fluorides are evolved during the phosphate fertilizer manufacturing process. A discussion of the extent of, state of, and usefulness of knowledge in the natural sciences about the effects of airborne fluorides upon citrus and upon cattle is also included.

Chapter IV will present some of the writer's views on some of the problems associated with measuring air pollution damages. The writer will argue that the incomplete present state of this knowledge gives the economist little choice but to use land values in attempting to determine these damages. But, in addition, the writer will argue that even if reasonably complete knowledge about the systemic effects of toxic airborne materials was available, the estimation, on a fairly disaggregated level, of receptor damages still makes the use of land values preferable.

Chapter V presents and interprets what are perhaps the rather surprising results of a study of the apparent relation between intensity of air pollution and Polk County land values.

Chapter VI, the final chapter, will present a short reveiw of some of the proposals which others have advanced for the purpose of controlling air pollution. Finally, an attempt will be made to present the writer's views about the implications of the results of Chapter V for these control proposals and their applicability. The basic conclusion will be that the most efficient control measure to take in many air pollution situations might be to simply impose a constraint upon the aggregate of emitters which limits the volume of pollutant materials they may emit as a group over a given interval of time. Most of the other devices, such as emitter charges, which have been proposed would, it will be seen, involve both receptors and emitters in conjectural variations, a problem whose results are generally acknowledged to be usually indeterminant. In contrast, the imposition upon emitters of a simple scarcity constraint having somewhat the same form as those presently advocated by engineers would in many circumstances enable a reasonable approximation of a perfect market to be attained and maintained. Throughout, rather than focusing upon an increase in the economic efficiency with which the air resource is to be allocated, the intent is to look at the various criteria which have been proposed and/or employed for purposes of air pollution control and to determine their effects upon the significant conditions which may facilitate or impede this allocative efficiency.

CHAPTER II

THE ECONOMIC NATURE OF AIR POLLUTION

One of the favorite plays of all those who have ever taught courses in elementary microeconomic theory is to use air as a means of pointing out the distinction between an economic good and a free good. The air resource, since it supposedly had no valuable alternative uses and since it was supposedly available in sufficient quality and quantity to satiate every individual's needs was thought to fulfill nicely the concept of a free good--a good which therefore was of no concern to economists.

With some reflection, it appears the economist's well-worn example of air as a free good constitutes a misinterpretation of the layman's phrase, "as free as the air." What the economist thought the layman meant was that more air was available than the sum, whether weighted or unweighted, of individual wants at the smallest conceivable positive price. But what the layman actually meant is that air was, for the most part, free for the taking: that is, since nobody owned the air, nobody could control its use--there were no constraints, economic or otherwise, placed upon the manner in which the individual could use the air. Reasoning inductively, the economist felt that since no apparent or recognizable price was attached to the use of the air, the air must be a free good; but the layman, reasoning intuitively, was sufficiently perceptive to note that since the air was everybody's and therefore nobody's property, he could use it and alter it in any way he saw fit. Bascially, although the layman treated the air as if the economist's concept of its economic nature was correct, he was intelligent enough to realize that is was only the structure of economic institutions which made the economist's concept appear, wrongfully, to be correct.

Actually, air hasn't been a free good since the first caveman made a metal tool, for the air, or rather the oxygen which makes up one-fifth by volume of the air, caused this tool to deteriorate with the passage of time. Since the prevention of this deterioration would have required the use of positively priced inputs such as the labor and the materials required for the construction of an air-tight casing, the simple presence of air does and always has necessitated taking into account the proper use of resources having valuable uses elsewhere.

However, the above is not to say that the air in which the caveman found himself immersed had properties posing problems similar to those we face today. The natural makeup of the atmosphere was such, except when volcanic eruptions occurred and perhaps in the farthest reaches of his caverns, as to not endanger the caveman's life of the life forms upon which he was dependent for his livelihood. The modern air pollution problem results from the fact that the contemporary world has accentuated the air's artifact destroying properties and has injected a new dimension into the problem by changing the air's makeup in a manner causing it to have deleterious effects upon biological entities. The efficient cause of this phenomenon is the desire of man to make use of the air's waste disposal capacity as one of the major means of ridding himself of those side-products having a nonpositive value of specific production and consumption processes. That is, for all existing potential pollutant units and for all expected potential pollutant units whose recovery possibilities can be influenced by present and/or contemplated actions, the present value of incremental private recovery costs is greater than the present value of incremental private recovery benefits.

But the air or rather the collection of gases and particulate materials which compose the air, as distinguished from air space, is that type of flow or renewable resource whose future physical attributes are little, if at all, affected by its present use or state. The air resource is thus different from other flow resources such as timber and wildlife in that the interdependencies between and among dated states of the air resource are generally quite insignificant, if present at all.[1] Pollutants, whether of natural or human origin, collect in the air constantly. But winds, rains, and other atmospheric phenomena disperse, dilute, and occasionally act as reagents for these pollutants, so if no more pollutants are emitted, the air overlying a particular land space will ultimately be cleansed of all foreign gases and materials. However, these cleansing agents make the air resource even more unlike other self-renewable resources such as water and timber in that man is incapable to any important degree of storing or transporting these cleansing agents or of modifying their elemental nature.[2] Therefore, in addition to being independent of each other in a purely physical sense, dated states of the air resource are economically independent of each other as well.[3] Thus the problem man faces with respect to these air cleansing agents is for him a quite uncommon one. With most resources, whether renewable or nonrenewable, he potentially is able to modify their elemental and/or locational characteristics to some significant degree in order to suit his economic needs. But with the air and its pollution, man's actions, institutions, and artifacts must be modified. He is unable to adjust the winds to any appreciable extent; therefore he must adjust himself to the whims and vagaries of the air currents. His inability to face up to this fact appears to be the root cause of the air pollution problem.

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[1] The global atmospheric loading of carbon dioxide is sometimes thought to constitute an exception to this generalization though.

[2] *Time* reports at least one imaginative engineer has proposed that Los Angeles, a city noted for the supposed severity of its air pollution problem, construct huge fans to blow pollutant materials from the Los Angeles basin. However, the daily amount of power required just to run the fans would be equivalent to the annual output of eight Hoover dams. See "Menace in the Skies," *Time*, 89 (Jan. 27, 1967).

To the best of this writer's knowledge, no one has ever estimated the volume of air over any one interval of time likely to be available in the United States to man and his property. In addition to the relatively simple task of determining the number of cubic miles of "standard" air, there would be the problem of calculating the probable values of a number of meteorological parameters. Until such time as the total volume of air is established, the spread of stories, even though true, which tell of 400,000 tons of pollutants being released daily by man throughout the nation must be of rather questionable value.[4] When several hundred thousand tons are balanced against an unknown number, the impact of the tons is likely to be several times what it would be several times what it would be in the true dilution-capacity relationship: the value which the unknown assumes in the minds of most people is likely to be much closer to an immutable zero than to a highly variable large number. When this lack of knowledge about even the atmospheric resource's physical attributes is combined with the attitude that one should not place an economic value upon the air, the result is too many proposals for the control of atmospheric pollution based upon concepts of physical rather than economic scarcity and upon nonrenewable rather than renewable resources. If carried to their logical conclusions, such views mean that our economic welfare will be determined by a system built upon a "pure" air theory of value--a theory which is even less desirable than the labor theory of value. Rather than being directly dependent upon the absolute quantity of pollutant materials released into the atmosphere, air pollution is a function of both time and space. Whether the alteration of the proportions of elements in the atmosphere actually constitutes pollution depends upon the alteration's nature and extent, on the purposes for which the air mass is subsequently required, and on the air mass's previous state.

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[3] In this sense, the air resource can be said to be more a fund than a flow resource because, in the long-term, meteorological phenomena in any given locale do tend to exhibit many stochastic if not deterministic regularities.

[4] Kimmis Hendrick, and Robert C. Cowen, "Cities Designed for Breathing," The Christian Science Monitor, (March 31, 1965), p. 9

The air has two key economic dimensions: a life and property supporting ability and a waste disposal ability. The unresolved conflict between pollutant emitters and pollutant receptors exists because both of these dimensions are considered by the emitters or receptors to be free goods. To emitters, over some interval of use both of these dimensions have a positive value; but to receptors, only the life and property supporting capacity is of positive value, while the waste disposal capacity is of negative value in the same sense that the housewife--or her husband, if he is the one who has to wash the dishes--considers the washing of dishes to have a negative value. A negative value of any good is possible if and only if its disposal requires the use of a good having a positive value. Washing the dishes takes the husband away from his newspaper and his nightly bottle of beer. Allowing the emitter to release his wastes into the air means the recepter must do without cleaner air. But just as the housewife considers her husband's function in washing the dinner dishes to have a positive value, the emitter of wastes considers the function of air as a waste disposal unit to have a positive value. Or, just as a reduction in the number of dishes to be washed has a positive value to the husband, a reduction in the volume of air devoted to waste disposal purposes has a positive value to receptors. Thus it is worthwhile for receptors to have the volume of air used for waste disposal purposes reduced, but it is worthwhile for emitters to have this same volume maintained or increased.

In the present state of affairs, the receptor receives free the use of a volume of air on which he places a positive value. At the same time, the emitter is given a good which has a positive value for him, but a negative value for the receptor. Thus both groups or parties can consume at a zero price something which is economically scarce. Economic waste is therefore inevitable. Neither party possesses a means of resolving the conflict to their mutual satisfaction--other than the extremely tedious, time-consuming and socially costly method of attempting to convince the public and its designated authorities of the dire consequences of reducing and/or not increasing the availability of that dimension of the air which to the party in question is more valuable. That is, the present state of affairs makes it worthwhile for emitters to complain about being forced to make "nonproductive" investments in air pollution controls. Simultaneously, it is worth the while of receptors to bewail stridently and shrilly the lack of cleaner air.

But the obvious fact that society provides the air's two value dimensions free and without discrimination between receptors and emitters in no way explains why society has done so. Since an increase in the volume of air proivded over any one interval of time for one of the two dimensions necessitates a reduction in the available volume of the other dimension, that condition of scarcity so necessary to the formation and maintenance of a market in legal rights to the use of the air is clearly present. One would therefore expect the market to do a fairly adequate job of allocating the air's two value dimensions according to the criteria of economic efficiency. That is, receptors and emitters would be expected to exchange rights to the life and property supporting dimension and the waste disposal dimension until such time as the present value of the difference, however measured, between emitter total cost-savings and receptor total damage costs, however defined, was maximized.

The receptor total damage cost function relates the returns the receptor is forced to forego because of air pollutant fumigations over some given interval of time to the pollutant materials released into the atmosphere by the emitter. Similarly, the emitter total cost-savings function relates the costs the emitter can avoid by releasing various quantities of pollutant materials into the atmosphere to the volume he does release over some given interval of time. The marginal form of the receptor total damage cost function thus shows the additional compensation receptors would have to receive in order to be indifferent between being subjected to or not being subjected to an additional unit, however measured, of pollutant fumigations. In the same sense, the marginal form of the emitter total cost-savings function shows the additional compensation emitters would have to receive in order to make them indifferent between releasing or not releasing into the atmosphere an additional unit of pollutant materials. Thus, according to the initial distribution of rights to the use of the atmosphere, the marginal damage cost function can be regarded as either a supply function or a demand function. If all use rights are legally the receptors', then the marginal damage cost function is the supply function faced by emitters for the release of pollutant materials into the atmosphere. The marginal cost-savings function is then the emitters' demand function for such releases. But if all use rights are legally or effectively the emitters', then the marginal cost-savings function is the supply function faced by receptors for rights not to have greater atmospheric pollutant loadings, while the marginal damage cost function is the receptors' demand function for these rights.

If the legal system gave emitters uninhibited rights to the use of the air resource, receptors would find it worthwhile to pay emitters to reduce emissions so long as additional payments were less than additional reductions in damage costs. And emitters would accept this payment as long as it continued to be greater than control costs. Or, as is more likely the actual case, if the legal system gives the receptor an absolute right to unadulterated air, emitters would be willing to pay receptors for the right to release pollutants until additional payments became greater than initial control costs. Receptors would find such payments to their liking until an additional payment failed to cover the additional damage costs. Clearly, given that no party is presently and/or potentially able to exercise any monopolistic advantage, the question of which party initially possesses the right to the use of either one of the air's two value dimensions does not seem to affect the ultimate allocation of these two dimensions. The net economic returns from the resource are being maximized in either case because neither party can benefit from further exchange. Although the initial delimitation of rights affects the distribution of gains and losses as between and among receptors and emitters, it in no way seems to affect the degree of allocative efficiency implicit in the ultimate conclusion. To the extent such exchanges do take place in actual air pollution situations, society need not bother itself about a supposed failure to maximize the social surplus. According to the initial delimitation of rights, receptors and/or emitters must include in their cost calculations (and in their output decisions) the opportunity costs of failing to accept payments for allowing emissions in the case of receptors, or, in the case of emitters, of refusing payments for reductions in emissions. In either case, each party has included in his cost calculations the effects of his actions upon the other party; and each party is doing so in just the manner the other party would do if this other party was simultaneously both parties. Any attempt to go beyond or stop short of the quantity of emissions resulting from this ideal exchange process would bring about a transfer of value to one party less than that given up by the other party.[5]

A second case in which society need not be too concerned about a failure to exploit what many might insist to be a socially profitable reallocative opportunity occurs when under nearly all conceivable conditions the costs of establishing and maintaining a market or a control system leading to the results of an ideal exchange process are impossibly high. That is, if transaction costs or the costs associated with running a nonmarket control system are so high that they negate all net benefits from actual or simulated exchange, the criteria of allocative efficiency would be better fulfilled by the expedient of letting things slide or by simply forbidding certain actions. Information gathering and attempts to obtain more precise controls should continue only until such time as the present value of the additional costs of gathering the additional information necessary for the more precise controls is equal to the present value of the additional social net returns flowing from the increase in the likelihood that more precise controls will actually be forthcoming. We might, of course, make the strong assumption that the state or the body to which it has delegated the authority to deal with air pollution is able to obtain sufficient information about the problem's economic and meteorological parameters to enable the control body to operate solely within the context of risk. But we have, by stating the entirely reasonable hypothesis that the body responsible for control will have to spend somebody's money in order to accumulate and analyze information on relevant sets of events, reintroduced into the problem that cloud which corrupts so many of the clean and clear creations of planners--uncertainty.

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[5] Nearly all of these same points have previously been made by R. H. Coase in his "The Problem of Social Cost," Journal of Law and Economics, 3 (Oct. 1960), pp. 1-44.

With the introduction of information costs, the formal allocation or reallocation problem is now recast into a much more complex problem in which the costs of achieving the optimal allocation must be included. If the factors of production employed in attempts to acquire and analyze information which might bring about greater control precision have alternative uses consistently more valuable than is greater precision in resource allocation, the net returns to improved (in the narrow sense) resource allocation are negative and can therefore hardly be termed economic. Thus it is entirely conceivable in many air pollution situations and in many other situations in which negative technological externalities are somehow thought to be present that the best corrective action to take may be to do nothing or to make some arbitrary--in the economic sense--rule. Unless one insists that the funds employed for attaining and maintaining greater precision in control arrive precisely as did manna to the Israelites, then he must recognize that economic efficiency might require inequalities rather than equalities among those marginal conditions arrived at only by failing to take into account the costs of attaining and maintaining them. If the costs of acquiring and analyzing information negate the benefits from adjusting a previously optimal control policy, then--abstracting from information costs--this control policy is no longer optimal, even though it is optimal, given its previous existence, when information costs are included. However, without having complete information, there is no *a priori* reason to think that the control policy which was formerly optimal continues to approximate an optimum better than any other control policy set at any arbitrary level. In the case of air pollution, the costs of acquiring greater precision might necessitate for many locales simply leaving the emitters alone to do as they wish, forbidding all emissions whatsoever, or setting some acknowledged arbitrary positive limits upon the actions of emitters and/or receptors. Economic objectivity is of no assistance in selecting among equally arbitrary alternatives. Or, if one insists upon estimation of all the relevant parameters despite information costs, his scientific objectivity can be purchased only at a substantial sacrifice in economic objectivity.[6]

Nevertheless, to argue that the costs of achieving greater precision in air pollution control might make it worthwhile to choose among the variety of alternatives for such control on a strictly arbitrary basis is not to say these precision costs must always negate the returns from greater precision. Nor does such an argument provide any indication of the sets of circumstances in which one might legitimately raise the question as to whether or not greater precision is worth attempting. An indication of this sort can be acquired only by obtaining an understanding of the major obstacles to efficient allocation inherent in the air pollution problem. That is, if market prices and quantities are to be employed in order to allocate the air resource between and among uses and users, one must have a thorough understanding of the biases--in terms of deviations from an ideal exchange process--introduced into these prices and quantities by the economic structure of the air pollution problem. And, in order to do this, one must comprehend the causes of the structure itself.

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[6] In this and preceding paragraphs, it has been implied that greater precision and greater accuracy are somehow synonymous or at least commensurate. Yet, if greater precision is treated as being concerned with improved specification and identification of relevant relations, while greater accuracy refers to the reduction in the errors of the estimated coefficients for the variables in these relations by improved sampling and/or estimating procedures, then attempts to achieve greater precision may substantially increase the risk of lesser accuracy. The greater is the number of parameters to be estimated and the greater the number of these parameters whose estimates are dependent upon each other, the greater is the risk of erring badly. The accuracy with which a parameter is estimated that is a function of another already estimated parameter cannot in fact be any greater than the estimate for the already estimated parameter. Any attempt to reduce the error of the "dependent" parameter below that of the already estimated parameter is a waste of economic resources, even if the attempt can be made at zero money outlay.

What at first glance in the air pollution problem appears to be a simple matter of causing the production processes of emitters and receptors to be physically independent rather than interdependent is really a matter of finding a means for efficiently allocating between and among emitters and receptors a jointly used presently indivisible input--an input the value of which is not intrinsic, but which is instead derived from the net returns those inputs whose productivity can be affected by the quality of available air are expected to earn in production. Because of the presently existing absolute indivisibility of the air resource, only the inputs which use either or both of the air's two value dimensions are scarce to individual receptors and emitters. Although the air resource in each of its two value dimensions is a scarce good to society, it is a free good to the individual receptor and/or emitter.

The indivisibility of the air resource causes the air pollution problem in its economic aspects to be bedeviled by practically every type of market failure which economists have been able to conceptualize.[7] In most cases, at present, individual users of one value dimension have no way to compensate users of the other value dimension so that it is worthwhile for the latter to make available the volume of that dimension which the former regards as most valuable. That is, the individual receptor can't dig up enough money on his own to make it worthwhile for the emitter to reduce his emissions. Similarly, the individual emitter who is only one of several emitters is usually unable to finance alone a payment of a size adequate to persuade all receptors to accept payments for suffering from the air pollution for which all emitters are responsible. Furthermore, even if the individual user of one of the air's two value dimensions is able to pay enough to cause the volume of that dimension he regards as most valuable to be made available, he has no way of preventing the benefits of his transaction in the air resource from accruing to fellow users who do not participate in the transaction. Generally known as the public goods or the free rider problem, this fact alone would in many situations prevent the occurrence of any trading in externalities. No means exists to bring about cooperation among receptors and among emitters to whose advantage it is not to cooperate with each other. That is, it is worth the while of the individual receptor and the individual emitter not to purchase an externality because there is always the possibility that his neighbor will purchase one, and vice versa. Since the individual who would otherwise purchase a right to the use of the air resource is unable to appropriate all its benefits for himself, he is willing to sit back and allow his fellow receptors or emitters to spill some benefits upon him. Any one receptor's or emitter's needs cannot be satisfied apart from other receptors' and emitters' needs. Each receptor and emitter has an incentive to take no action, for he will maximize his share of net returns from the air resource by doing nothing while others do everything. But the very universality of this incentive prevents anything being done, i.e., no action will be taken. No one is willing to act unilaterally, but every individual might well be prepared to act if everybody else does.

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[7] The usual trichotomy of common property externalities, technical externalities, and public good externalities was originally set forth in F. M. Bator's excellent classificatory article, "The Anatomy of Market Failure," Quarterly Journal of Economics, 72 (Aug. 1958), pp. 351-379.

To the extent the apparent advantages of a free ride outweigh in receptor minds the advantages of individual or collective action, the emitters can treat the air's waste disposal abilities as common property freely available to all wishing to use them. This common property problem enters in that it is extremely difficult to define property rights in the mobile gas known as air, as distinguished from simple air space. Presumedly, a secure property right in air would have to be defined in terms of rate of use, the interval of time over which such use could occur, the interval between the times at which use could occur, or alternatively, a set of natural events upon the occurrence of which the use of the right would be conditioned. Lacking this seemingly impossible degree of precision however, the receptor and the emitter have few economic means available whereby they are able to defend their supposed exclusive use rights to the air overlying their property at any one moment of time.[8] That type of title which dominates United States real property rights is the fee simple absolute, under which the individual is assumed to have "an absolute interest in something which the law calls real and which includes soil, whatever is below the soil, the use of run-off water and waters circulating through the soil, the use of stream waters flowing through the close, the atmosphere above the close, and as much of the air space as can be used or is needed for security. All of this is encompassed by Coke when he says that the fee simple absolute extends from Heaven to Hell."[9] Thus the fee simple absolute provides its holder with an opportunity voluntarily to capture all the benefits while at the same time bearing all the costs which the title enables him and forces him to internalize. Thus, if he wishes, states the unconditional interpretation of the doctrine, he may place into that air within the air space to which he has title any and all types of noxious and toxic gaseous and particulate matter without bothering to concern himself with what happens to it after it deserts his air space. And, similarly, he and his artifacts must involuntarily ingest and absorb much of the noxious and toxic gaseous and particulate matter which adjoining or nearby property owners place into the air which happens to be flowing through their air space and which, unfortunately, must eventually enter into the air space above his own property. To the extent these materials are harmful, he, if he employs the same mix and quantity of inputs as before, will find that his output is reduced; or, if he insists on maintaining his output in the face of all odds, more inputs and probably a different mix of inputs will be required. In essence, he is forced to submit to an involuntary reduction in the dollar value of output he obtains per dollar spent on inputs and/or a reduction in the incremental dollar value of output for each additional dollar he spends on inputs.[10]

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[8] As some familiarity with a particular area's air pollution problem will make abundantly clear, the primary means of defense are legal through the nuisance doctrine and/or political through attempts to convince governmental or legislative bodies to initiate laws having legal force and standing.

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[9] Earl F. Murphy in a personal communication dated June 7, 1966.

[10] This is the usual distinction between intramarginal externalities which affect only the firm's net revenues and intermarginal externalities which affect the firm's marginal costs and output as well as its net revenues. In air pollution, the intramarginal case occurs when, for example, the pollution reduces the quality of output the receptor can obtain from a given mix of inputs or when it necessitates the purchase by the receptor of some fixed input resulting in a vertical displacement of his total cost function. The intermarginal case, on the other hand, affects the receptor's technical coefficients of production, i.e., it affects the marginal physical products, marginal costs, and marginal value products associated with a variable input.

In Bator's words, the distinguishing feature of the common property form of externality is nonappropriability or nonexclusibility reflecting a lack of adequate organization and due to "the divorce of scarcity from ownership."[11] This divorce brings about a situation in which "the conservative dictum that everybody's property is nobody's property"[12] appears to be fulfilled: that is, the resource is exploited until the social surplus or rent which would otherwise accrue to it is totally dissipated. The dissipation occurs because each individual user of the resource can and is actually encouraged to treat the resource as a free good. He can do this because of the lack of presence of an agency or owner to whom society has seen fit to assign the right and the power to collect the rent or surplus. Thus each and every individual user of the resource voluntarily continues to capture and/or to use the resource over any one interval of time until the present value of the incremental costs of those non-resource factors of production employed by the individual are equal to the present value of the marginal value products to be obtained from these same non-resource factors. Since no price is attached to the use of the resource itself there is no cost accruing to the individual user by further exploitation. He thus continues to exploit it so long as any surplus remains. Furthermore, in the case of an exhaustible common property resource such as the passenger pigeon, ground water, or the waste disposal ability of a given volume of air, the present value of the resource's future availability is to the individual user zero because "he who is foolhardy enough to wait for its proper time of use will only find that it has been taken by another."[13] In other words, if for some reason, idealistic or otherwise, the individual resource user sets the time at which he will achieve a given volume of use farther into the future, he will simply accentuate the costs other users are imposing upon him. The other users, in addition to making his present uses more costly, would by dissipating the resource's rent remove much or all of his possible future returns. Thus each individual resource user in order to minimize the costs that are imposed upon him must immediately take as much of the resource as his non-resource factors allow him to get.[14] Prescriptive rights or a queue are substituted for an auction or market system as a means of allocating the resource. And if and only if speed is the sole variable of which marginal value productivity is a function will the order of priority for users established under the queue correspond to the order of priority for users established under an auction system based on marginal value productivity.

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[11] Bator, op. cit., pp. 363-365

[12] H. Scott Gordon, "The Economic Theory of a Common Property Resource: The Fishery," The Journal of Political Economy, 62 (April, 1954), p. 135.

Most attempts to ameliorate externalities caused by the existence of common property involve an endeavor to get at the heart of what caused the problem in the first place: insufficient or inadequate definitions of property rights. The common law basis of their endeavors involves modifications of the fee simple absolute in a manner which partially or wholly restricts the uses to which a site owner can put his overlying air space if such uses result in physical or perhaps even esthetic [15] invasion of his neighbors' air space.[16] However the court then inevitably states that a person in an urban center cannot insist upon the same standard of air quality as may the outlying suburban resident.[17] What is a sin is not a sin if it is done in the right place. In the last analysis, the conditions under which the courts consider a neighbor's claim to clean air to be a valid claim depend on what the courts consider worthy of protection. Decisions are easily found in which an emitter of substantial economic importance to a community was enjoined from further operations because of the damages suffered by a single small neighbor.[18] On the other hand, at least as many cases can be found in which the interests of the plaintiff--though he is generally awarded damages--are thought to be far outweighed by the economic contribution and necessity of the emitter's operations.[19]

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[13] Ibid.

[14] There does exist a very minor exception to this case. If for all possible positive levels of use in the present the rent from the resource is insufficient to cover the average costs of the non-resource factors, then the resource would not at present be exploited. Every potential resource user would find it advisable to wait for the moment when the surplus was sufficient to cover the average costs of his nonresource factors. But when this moment arrived, the individual user would still have to move as fast as he could in order to obtain his share.

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[15] See Rauh & Sons Fertilizer Co. v. Shreffler, 139 F 2nd 38 (1943), where the defendant was accused of "faithfully emanating a nauseous stench."

[16] "The ownership of land carries with it the rightful use of the atmosphere while passing over it. Title to land gives to the owner the right to impregnate the air upon and over the same with such smoke, vapor and smells as he desires, provided he does not contaminate the atmosphere to such an extent as to substantially interfere with the comfort or enjoyment of others, or injure the use of their property. But air is movable, and constantly flowing from the premises of one to those of another, and hence when it becomes thickly impregnated with putrid substances, it necessarily flows onto the adjacent premises in one direction or another. This being so, it follows that any business which necessarily and constantly impregnates large volumes of the atmosphere with disagreeable, unwholesome, or offensive matter, may become a nuisance to those occupying adjacent property, in case it is so near, and the atmosphere is contaminated to such an extent, as to substantially impair the comfort or enjoyment of such adjacent occupants. When such comfort and enjoyment are so impaired, and compensation is demanded, it is no defense to show that such business was conducted in a reasonable and proper manner, and with more than ordinary cleanliness, and that the odors so sent over and upon such adjacent premises were only such as were incident to the business when properly conducted. It is the interruption of such enjoyment and the destruction of such comfort that furnishes the ground of action, and it is no satisfaction to the injured party to be informed that it might have been done with more aggravation. The business is lawful, but such interruption and destruction is an invasion of private rights, and to that extent unlawful. It is not so much the manner of doing as the proximity of such a business to the adjacent occupant which causes the annoyance. A business necessarily contaminating the atmosphere to the extent indicated should be located where it will not necessarily deprive others of the enjoyment of their property, or lessen their comfort while enjoying the same." See Pennoyer v. Allen, 56 Wis., 502, 14 N.W. 609 (1883)

[17] See, for example, Higgins v. Decorah Produce Co., 214 Iowa 276, 242 N. W. 109 (1932).

Because, in effect, the law assigns private rights only to air space and not to the mobile gases within that space, the legal aspect of air pollution problems would seem to involve more a breach of contract between an offended private party and the state rather than a breach of a privately made contract. But since courts have tended to act on the basis of ad hoc decisions, no consistent pattern of decisions emerges. In general, the whole problem area appears to be rather a lawless one. The nuisance doctrine, which most lawyers would agree is "an ambiguous body of doctrine intended to provide a method for restraining harmful activities on land,"[20] allows the courts to reach only existing nuisances, leaving future acts to be the subjects of new prosecutions or proceedings.[21] Furthermore, since the offended private party generally cannot bring suit unless he is able to show that he has sustained special damages--he thus seldom has a cause of or a course for action when the quality of the air over his site is similar to that of the surrounding atmosphere--the "little guy" is rarely able to expend the funds, time and energies necessary for the successful development of his case. The fact that the great majority of those cases in which the courts have actually rendered decisions involve situations in which the bargaining strength of one of the parties was extremely weak or dissipated relative to the bargaining strength of the opposing parties is evidence that the party with the greatest bargaining strength has relatively little to fear in courts. Most out-of-court settlements involve parties of approximately equal bargaining strength.

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[18] See Hurlbert v. California Portland Cement Co., 161 Calif. 239 (1911), in which the court asserted that to permit the defendant cement company to continue operations "to the extent of destroying the property of the plaintiff and requiring payment for the full value thereof would be, in effect, allowing the seizure of private property for a use other than a public one--something unheard of and totally unauthorized in the law." Continuing with its argument, the court stated that "every substantial, material right of a person or property is entitled to protection against all the world. It is by protecting the most humble in his small estate against the encroachment of large capital and large interests that the poor man is ultimately enabled to become a capitalist himself." The court assumed this point of view while simultaneously admitting that the cement company was not negligent in its operations, and, in fact, employed the most modern emission control equipment.

[19] See, for example, Madison v. Ducktown, 113 Tenn. 331, 83 S.W. 653 (1904). Here the court argued that "in a case of conflicting rights where neither party can enjoy his own without in some measure restricing the use of the other in the use of property, the law must make the best arrangement it can between the contending parties, with a view to preserving to each one the largest measure of liberty possible under the circumstances." An unequivocal statement of this view is available in Gibson, et. al. v. City of Tampa, 154 So. 842. "A court of equity may properly refuse to grant an injunction when it appears that greater injury and inconvenience will be caused to the defendant by granting the injunction than will be caused the complainant by refusing it."

In summary then, unless the parties involved are using the threat of court action as a bargaining tool, an approach which attempts to ameliorate air pollution by means of the common law and the courts must essentially be dichotomous. If the court issues an injunction against the emitter, the emitter must usually cease releasing all pollutant materials into the atmosphere. As often as not the cessation of such releases requires the cessation of all the would-be emitter's operations. On the other hand, if no injunction is imposed, the receptor, if he maintains his location, has no choice but to continue to be subjected to pollutant fumigations. The only situations in which questions of degree can be said to enter into the legal deliberations occur when the court requires the emitter to compensate the receptor for *ex post* damages. However, the *ex post* nature of the payment is still dichotomous in the larger sense because of the court's inability to take expected damages into account.[22] Since it is the rare receptor who could afford to bring suit each time he suffers damages, the actual effect of attempting to employ only the common law and the courts to ameliorate pollution problems closely approximates either doing nothing about pollution or requiring that no pollution whatsoever exist.

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[20] Daniel R. Mandelker, "The Role of Law in the Planning Process," Law and Contemporary Problems, 30 (Winter 1965), p. 29.

[21] Mugler v. Kansas, 123 U.S. 623, 673

The seeming inability of the common law to provide representation for parties who are now "out-of-court" with no standing, or inadequate standing, or insufficient economic resources, but who for some public reason should have representation in decisions about the air resource, has necessitated the use of the police power and the construction of statutory laws and provisions for the control of air pollution. In this manner, the state or some legally constituted arm of the state is explicitly given jurisdiction over the air resource. That body which is given jurisdiction may then permanently retain jurisdiction; or it may define property rights in a manner which would allow these rights to be wholly or partially parceled out to existing and/or potential resource users. Ideally, in the first case, the enforcement or control agency would specify all utility and production functions in the relevant locale, solve for the maximization of the air resource's rent, and then issue instructions to all decision units telling them how to act in order to achieve the maximization.[23] In a similar ideal manner for the second case, the enforcement or control agency would specify all utility and production functions in the relevant locale, solve for the maximization of the air resource's rent, select that device such as a tax or standard which would cause decision units to choose to act in the prescribed manner, and then sit back observing the decision units achieve the already known maximization solution. If the reader objects that both of these procedures require that the control agency possess omniscience, his objection is inalterably and utterly correct.

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[22] This is somewhat of an overstatement since courts do occasionally measure damages by the difference between *ex ante* and *ex post* land values. See, for example, *Ehorn et. ux* v. *Northwest Magnesite Co.*, 230 Pac. 419 (1922).

Though the internalization of the costs and benefits of air pollution by the formation of a control agency does provide one of the necessary conditions for the maximization of that formerly dissipated social surplus or rent from the air resource, it by no means provides all the necessary conditions.[24] In addition to the by now well-known case where the meeting of the optimum conditions in one sector requires departures from these optimum conditions in other sectors, the departures possibly involving a net loss of welfare,[25] the control agency will have to act occasionally on the basis of imperfect information and signals and will have to give some attention to political realities--it will have to, that is, unless it is and always will be omniscient and all-powerful.

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[23] Some penalty would have to be available for failures to obey the instructions. The value of this penalty to each decision unit would have to be greater than the potential benefits accruing to the decision unit's failure to obey.

The basic reason for the formation of the control agency is the relative absence of a reasonably effective private market for rights to the use of the air resource. Unless the control agency is able to define finally these use rights in a way which will bring about the formation and the maintenance of an effective market, it will have to attempt to determine the relative values receptors and emitters place on these use rights either by directly measuring receptor and emitter utility functions and production possibilities and/or by allowing and observing political expression about these values in the form of hearings, petitions, "studies," referenda, and other forms of representation. This latter device makes the decision-making process take on many of the problems associated with the determination of the optimal provision of a public good, for the process participant can alter the relative prices of the air resource's two value dimensions and therefore the set of alternatives he has facing him. In an effective private market this would be impossible, or at least unlikely.[26]

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[24] Nevertheless, some of the literature, particularly in the field of urban economics, tends to convey the unfortunate impression that internalization alone--its supposed benefits are generally held to be due to economies of scale or size--is both necessary and sufficient. Generally, this conclusion is due to the devotion of attention only to possible reductions in the money outlays necessary to operate metropolitan area-wide services. The values, measured in terms of willingness to pay, implicit in having these services provided by subarea governmental units are completely abstracted from. Somewhat analogous arguments espousing the provision of water basin commissions and air basin commissions are often found in the resource field.

[25] R. G. Lipsey and K. Lancaster, "The General Theory of Second Best," Review of Economic Studies, 24 (Oct. 1956), pp. 11-32. In this writer's immodest opinion, much, though not all, of the literature concerned with the second best problem amounts to nothing more than clever repetitions of the obvious point that the economic world is complicated and, in fact, is prevaded by interdependencies. For those who consistently favor inaction, the second best argument has obvious appeal. One possible way of avoiding the argument's complications when dealing with only partial equilibrium problems is to assume explicitly that the incremental loss in allocative efficiency due to failure to fulfill the optimum conditions in other sectors is exactly equal to the incremental benefits flowing from that increase in distributive equity caused by the failure to fulfill the optimum conditions in these same sectors. In other words, if one is dealing with the air pollution problem in Polk County, Florida, he might assume that it is a matter of social policy and justice to allow Florida orange growers to be protected by tariffs from foreign competition and to have Florida phosphatic fertilizer manufactureres sell their products to an agriculture subsidized by the Federal government in a manner which causes this agriculture to substitute fertilizer inputs for areal inputs.

Since, as will be noted in later chapters, the continuous generation of meaningful unbiased information on receptor and emitter utility and production possibility functions is unlikely, the control agency, if it does not wish to appear completely arbitrary, will have to listen to and try to gauge political expressions and representations. And unless the opportunity costs and potential benefits of participants in the political process correspond exactly to what they would be willing to pay for and what they could gain from that value dimension of the air which they hold most dear, political expressions of value will not correspond to private market expressions of value. In fact, one can reasonably hypothesize that the extent of one's willingness to participate in these political activities will directly depend on the difference between one's desired position, given the costs of political participation and one's subjective estimate of his ability to influence suitably the control agency's decisions, and one's expected actual position. Though it is not our purpose here to specify the degree to which the outcomes of the various possibilities for political coalitions would correspond to the outcome of a highly effective private market, it does nevertheless seem intuitively apparent that the correspondence would not always be perfect.[27]

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[26] The literature dealing with the economic aspects of political processes has become quite extensive. See, for example, Anthony Downs, An Economic Theory of Democracy, (New York: Harper Row, 1957), 320 pp. James M. Buchanan and Gordon Tullock, The Calculus of Consent, (Ann Arbor: The University of Michigan Press, 1962), 360 pp.; and Jerome Rothenberg, "A Model of Economic and Political Decision Making," in Julius Margolis, ed., The Public Economy of Urban Communities, (Baltimore: The Johns Hopkins University Press, 1965), pp. 1-38.

Since it is not at all apparent that large doses of politically motivated decisions will bring about a result which is Pareto optimal, i.e., a situation in which there exist no further gains from trade,[28] it is in fact likely that the control authority has simply been substituted as the medium through which air pollutant receptors and emitters impose negative externalities upon one another. To the extent the distribution of political power does not correspond to what the distribution of purchasing power would be under a perfect economic market, then opportunity still exists for the parties involved to impose externalities upon one another. So long as one assumes that an individual will vote and/or apply political pressure for a measure which benefits him, will vote against a measure which removes existing or potential benefits from him, and will abstain from voting on a measure which neither benefits nor imposes costs upon him,[29] then any proposed measure which is adopted and for which less than complete unanimity prevails must make somebody worse off as it is making somebody else better off. That is, unless complete unanimity as to the measures to be adopted prevails, adoption of the measures and the configurations of rights to the use of resources which the measures imply must be Pareto suboptimal because at least one individual is being forced to participate in a transaction he would prefer to avoid.[30] In other words, without unanimity at least one individual must make an exchange he would not make and would not have to make in a perfect market because in a perfect market he would receive negative net benefits from the exchange, i.e., with political control old negative externalities are not likely to be entirely negated and/or new negative externalities are substituted for the old negative externalities found in the uninhibited imperfect market. In short, the internalizing of the externalities by the expedient of forming an air pollution control agency is unlikely by itself to remove the basic economic conditions giving rise to the air pollution problem; it basically does nothing more than change the form in which the problem is presented. The decision as to what is the best allocation of the air resource between and among uses and users must still be made.

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[27] For material on this topic, see the references listed in the previous footnote. The fact that the individual in the political process can alter the relative prices of the air's two value dimensions and therefore the set of alternatives he has facing him is not the only difficulty associated with the political process which makes Pareto optimal results unlikely. Two further difficulties are that the individual is unlikely to be able to invest the effort required to translate accurately alternative collective outcomes into personal benefits and costs, and that he will be unable to predict with accuracy the preferences of other individuals for and against particular outcomes. However, these latter two difficulties are also inherent in most real world private markets.

[28] Or, in the more popular contemporary manner of putting things, a Pareto optimum exists when it is not possible for any reorganization of institutional forms or any further shifting and movement of economic goods and the rights to the use of these goods to result in a situation in which at least one individual by his own lights is make better off without anyone else by his own lights being made worse off.

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[29] These assumptions have the effect of abstracting from all strategic situations similar to bluffing in a poker game. However, the strategy problem enters only when the form to be taken on by an act a group is later to make is expected to be some function of the form assumed by the act the group is presently making.

[30] The assumption of forced participation means that the individual has no voluntary withdrawal options open to him. Such voluntary withdrawal--unless it consisted of the sale of the individual's site--would be unacceptable and unworkable in most air pollution situations because of the public good character of the results of the decision process.

The preceding really amounts to little more than a twist upon the obvious truth that everybody would be better off if that which is scarce was not scarce. In this case, that which is scarce or perhaps nonexistent except in the heads of welfare economists is the necessary conditions for the attainment and the maintenance of a Pareto optimum. Thus if the necessary conditions for a Pareto optimum do not exist under any configuration of political forms and/or economic forms, the economic means of attacking the problem is to select that mix or configuration of control forms, whether economic, political, or both, with minimizes the extent to which divergence from the Pareto optimum occurs and will occur. This implies of course that the substitution of political or administrative control forms for the uninhibited though imperfect market should continue only so long as the net gains from the substitution are positive, i.e., only so long as the incremental reduction in the negative externalities occuring in the market continues to be greater than the increase in the negative externalities taking place through political control. The basic question then in air pollution control is not of an either/or nature, a choice between completely centralized control and individual receptor and emitter control or lack of control. It is a question instead of what the proportions will be in which private and collective decision-making elements are to be combined. The proportion of each element employed must be dependent upon the extent to which it can reduce the total receptor and emitter costs of using the air resource. The choice is not between two systems of control, one perfect and the other imperfect, but between two imperfect systems, each with its own set of errors. It is thus necessary to do more than simply test any two alternative decision-making systems against what are considered to be Pareto optimum results and reject them if they don't conform. Instead, in each problematic situation one must test each possible mix of any two alternatives against optimum results and accept the best of the mixes. If we look upon the populace of an area faced with an air pollution problem as being the owner of a mule with a split personality divided between receptors and emitters, we can state that the populace will not get the mule to move at an adequate pace by using the stick of imposed administrative or political rules. But neither will the mule move in the correct manner if the populace stands in front of the mule's nose offering him the carrot of unrestrained movement. Only if the rider sits upon the mule's back holding the stick with the carrot attached to its end will the mule take it upon himself to move correctly. The really relevant question is the proper length and thickness of the stick and the proper size of the carrot. It is not very helpful for one to kick aside attainable alternatives just because he happens to have an unfulfilled taste for the unattainable ones.

In summary then, this question of the degree to which it is efficient to substitute political and administrative controls for the demands of the market leads naturally and easily into the question of how decision rules are to be formulated once the most efficient mix of political, legal, and market forms has been decided. That is, even though the negative externalities formerly caused by the lack of coordination between and among many interdependent receptors and emitters may have now been made internal by the adoption of some form of administrative controls, the basic physicial conditions which originally brought on the atmospheric pollution problem still exist. Even though control over the air resource has been allocated on a scale sufficient to relate in an optimal manner the receptors and emitters to each other and therefore to the air pollution problem, all that the formation of some form of control authority has done is to change the environment in which the necessary allocation decisions must still be made. Even though the control program's administrators have a thorough understanding of the theoretical niceties of optimal allocation of the air's two value dimensions, the practical problem of discovering the actual optimal allocation over any one interval of time must still be wrestled with, and a means for carrying out this allocation must still be evolved. In short, merger for purposes of internalization of negative externalities might well be a necessary condition for these externalities' minimization, but, unless unanimity prevails after the merger, it is far from being a sufficient condition. Without unanimity, any attempt to achieve and to maintain efficient allocation of the air resource's two value dimensions requires identification and understanding of the alternative allocative devices which are available and the structure of the interests involved who need to be represented in the decision-making process. The knowledge required for efficient allocation of the air resource and the nature of its effects upon the parties involved in the allocation necessitates careful consideration of any particular air pollution problem's physical aspects and the structures of the economic activities that are affected by it. One locale in which there have been attempts to make these allocation decisions administratively has been Polk County, Florida. A recounting of the Polk County air pollution problem, what has been done about it, and the reactions among receptors and emitters to that which has been done provides substantial insight into the economic efficacy of the various devices which might be used to allocate the air resource's two value dimensions.

CHAPTER III

THE SETTING OF THE POLK COUNTY, FLORIDA AIR POLLUTION PROBLEM

More than any other area of Florida, the so-called central highlands region in which Polk County is located perhaps most closely approximates the travel brochure image of the state. Sunshine, oranges, palm trees, and plentiful recreational opportunities in the towns and around hundreds of clear lakes are all present in abundance. Knowledgeable travelers have in fact asserted that this is the only area of Florida in which man has furthered rather than destroyed natural beauty. Thousands of acres of citrus trees, evenly spaced in long undulating lines, have replaced the brush upon the gently rolling hills. The swampy margins of lakes in the towns have been filled, but those outside the towns have generally been left untouched. Pastures now cover thousands of acres of drained marshlands. The seeming anomaly of a tourist industry, intensively cultivated citrus groves, and extensive beef cattle ranges existing in close juxtaposition provides a rare example of the compatibility of highly specialized land uses. Some idea of the distribution of land uses throughout Polk County is provided by the following two not altogether consistent and comparable tables. A further idea can be obtained from Figure 1, although the borders supposedly separating land areas in which citrus is dominant from land areas in which beef cattle are dominant should be regarded as at best very broad generalizations.

But not all is idyllic in at least one part of this Polk County area. Approximately fifty miles southwest of Orlando and thirty miles east of Tampa is a four-hundred square mile area lying in Polk County's western portion and Hillsborough County's eastern portion which has

TABLE I

1964 POLK COUNTY ACREAGE ESTIMATES BY USE CLASSIFICATION

Use Class	Acreage	Per Cent of Total Acreage
Citrus	165,000	12.7
Woodland, pasture and forest	790,000	60.6
Marginal (Swamps, etc.)	94,000	7.2
Mined and mining areas	82,500	6.3
Major lakes	76,000	5.8
Highways and Roads	20,000	1.5
Incorporated Areas	43,000	3.3
Improved unincorporated areas	26,000	2.0
Miscellaneous	7,500	0.6
Total Acres	1,304,000	100.0

Source: Smith & Son, Appraisers, "Existing Land Use Study and Future Land Use Study of the Unincorporated Areas of Polk County, Florida." (Lakeland, Florida, June, 1965) p. 72. (Mimeographed.)

TABLE II

1958 POLK COUNTY ACREAGE ESTIMATES BY USE CLASSIFICATION

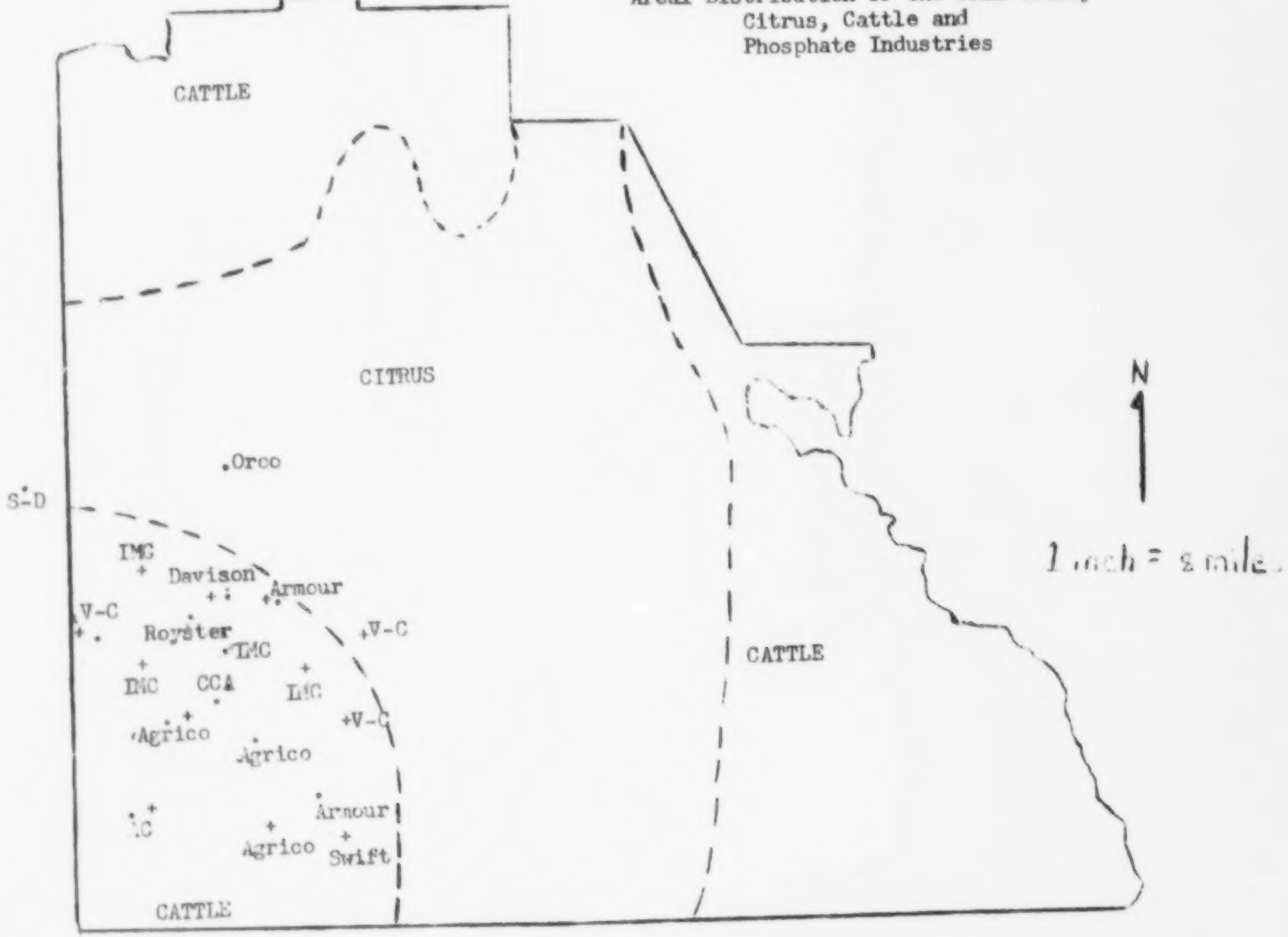
Use Class	Acreage	Per Cent of Total Acreage
Cropland, including citrus	150,800	12.7
Pasture and range	432,100	36.3
Forest and Woodland	457,700	38.4
Other land	55,300	4.6
Federal Land	27,600	2.3
Urban and built-up areas	63,600	5.3
Water Areas[a]	4,000	0.3
Total Acres	1,191,000	100.0

[a] Water areas of forty acres in size or one-eighth mile in width and over are not included in total land area.

Source: Florida Soil and Water Conservation Needs Inventory Committee, Florida Soil and Water Conservation Needs Inventory (Gainesville, Florida: Agricultural Extension Service, March 1963) p. 10.

Figure 1

Areal Distribution of the Polk County
Citrus, Cattle and
Phosphate Industries


CATTLE
CITRUS
.Orco
S-D
IMC
Davison
Armour
V-C
Royster
IMC
V-C
IMC
CCA
IMC
Agrico
V-C
Agrico
IC
Armour
Agrico
Swift
CATTLE
CATTLE
N
1 inch = 8 mile.

Key to Figure 1

A) The areas labeled citrus and cattle indicate only the dominant uses of agricultural land in these areas. The labels do not mean that one use or the other is the only agricultural land use found in the area in question. Substantial pasture lands are found in the citrus area, just as citrus groves can be found in the pasture areas. The dashed line separating one agricultural use from the other should therefore be regarded only as a quite loose approximation.

B) A cross(+) indicates the 1966 location of a phosphate rock drying and grinding plant.

C) A dot (.) indicates the 1966 location of a triple-superphosphate or concentrated superphosphate manufacturing plant.

D) The labels attached to the phosphate plant locations indicate the name of the company operating at the location. The names of the companies associated with the labels are as follows:

V-C = V-C Chemical Co.
Swift = Swift and Co.
Armour = Armour Agricultural Chemical Co.
S-D = Smith-Douglass Company, Inc.
Royster = F. S. Royster Guano Co.
IMC = International Minerals and Chemicals Corp.
AC = American Cyanamid Co.
Davison = Davison Chemical Division of W. R. Grace & Co.
Agrico = Agrico Chemical Co. (formerly American Agricultural Chemical Co.)
CCA = Consumers' Cooperative Association
OERC = Central Phosphates, Inc. (Occidental Engineering and Research Corp.)

been experiencing a scarcity of air since the 1950's. This scarcity constitutes a grave threat to the area's economic growth, for serious conflict exists between those who desire to use the life and property supporting capacity of the region's air resources and those anxious to make use of the waste disposal capacity of this same air. On the life and property side of the controversy stand the agricultural interests, mainly composed of the cattle and the citrus industries. On the waste disposal side stands the phosphate industry. These industries form the year-round base of the area's economy. Each has a long history in the area dating from the last decade of the nineteenth century, and each considers the area to possess an economic comparative advantage because of its unique environment.

I. BACKGROUND OF THE POLK COUNTY CATTLE INDUSTRY

The available quantitative information dealing with the Polk County beef cattle industry is extremely sparse. Nevertheless, since one of our major objectives is to discuss the impact of atmospheric pollution upon the output potential of this industry, it seems worthwhile to use, if only for purposes of providing general background, such information as is available. As will be obvious in the few pages to be devoted to this topic, nearly all of the materials from which information was obtained pertained chiefly to the Central Florida region, of which Polk County is a part. Therefore, since land usage in this Central Florida area is fairly similar as between and among counties, it seems reasonable to expect that the Polk County cattle industry would at the least not differ in kind from that of the rest of Central Florida. The only published quantitative information which the writer was able to find pertaining directly to the cattle industry of Polk County is presented in the following table, Table III. As the reader will note, the estimates of pasture acreage in this table are not in complete agreement with those in Tables I and II, just as Tables I and II were not in complete agreement with each other.

Agricultural production in Polk County tends to be highly specialized. Though a few farms raise a combination of crops, most of the operating units receive almost their entire revenues from a single class of product, or, in the case of citrus growers, from a single crop.[1] Though there appear to be a number of "farm herds" with fifty cattle or less, the majority are in large ranch herds which provide the major and often the only source of income for their owners.[2]

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[1] Of the 698 observed bona fide sales of Polk County agricultural lands sold from 1947 through 1964, 323 observations (46.3 per cent) were devoted solely to pasture, 219 observations (31.4 per cent) were devoted solely to citrus, and only 156 observations (22.3 per cent) were devoted to a mixture of pasture, citrus and/or cropland. For each three year period in the eighteen year 1947-65 interval, the proportion of observations devoted to each of these uses did not vary by more than ± ten per cent. However, slightly less than half of the observations in the mixed category for each three year period contained less than twenty acres not in citrus. Thus, one might well argue that many of those sites not entirely devoted to citrus either contained wasteland not suited for citrus or land which when citrus returns became fairly high would be devoted to citrus. In other words, about half the observations in the mixed category could readily be placed in the citrus category.

[2] L. H. Lewis, and N. J. Cunha, Beef Cattle in Florida (Tallahassee: Florida Department of Agriculture, 1958) p. 2; and L. A. Reuss, et. al., Florida's Land Resources and Land Uses, Bull. 555 (Gainesville: Fla. Agric. Exp. Sta., Nov., 1954) p. 24. In addition, the unpublished results of a telephone survey carried out in 1963 by the Polk-Hillsborough Air Pollution Control District and the Florida State Board of Health and in which 159 supposed Polk County cattle owners were contacted indicated that 89 (60.0 per cent) of these owners owned fifty or more cattle. Furthermore, seventy of these owners professed to receive at least three-fourths of their annual incomes from their cattle operations. The arithmetic mean size of the herds in the survey was 84.1 animals, with the largest herd having 1500 animals and the smallest only one animal. Only rarely did the records of personal

TABLE III

CENSUS DATA FOR THE POLK COUNTY CATTLE INDUSTRY

	1949	1954	1959	1964
Livestock farms[a]	1,220	1,176	952	797
Livestock ranches	NA	NA	104	NA
Cattle and calves on farms[b]	81,671	117,234	79,493	101,928
Cattle sold alive, except calves		21,158	14,030	15,917
Calves sold alive		30,632	22,076	27,805
Cropland for pasture in acres	66,637	60,857	78,550	36,703
Woodland for pasture in acres	517,472	578,430	330,640	278,672
Other pasture in acres	245,623	283,139	372,026	395,327
Improved pasture in acres	NA	53,095	79,612	107,496
Total pasture in acres	829,732[c]	975,521	860,828	818,198
Value[d] of livestock products sold[e]	$1,854,139	$2,494,031	$3,173,160	$3,487,738

[a] Other than poultry and dairy farms

[b] Excluding mild cows

[c] Excluding improved pasture.

[d] Nonconstant dollars

[e] Excluding dairy and poultry products.

NA Not available.

Source: Bureau of the Census, United States Census of Agriculture (Wash., D. C.: U. S. Gov't. Printing Office, 1951, 1956, 1961, and 1966 preliminary).

Because of the vast acreages in single ownerships--there is at least one ranch containing 15,000 acreas--Polk County as is Florida is classed as a range cattle area.[3] Florida is in fact the only state in the southeastern United States so classed. Of the approximately 1,300,000 acreas of land and water in Polk County, the U. S. Bureau of the Census indicates that for the past 25 years the primary use of between 800,000 and 1,000,000 of these acres has been the provision of feed for cattle.[4] Although about half of this acreage is close to the extensive margin between primary usage as woodland rather than pasture, a substantial portion of the acreage is well toward the intensive margin, since only citrus uses and urban uses rather than cropland uses are higher orders of use.[5] However, I will subsequently argue that some of this pasture acreage has become more valuable as a dumping ground for airborne pollutants rather than as grazing land for beef cattle.

Of the three principal types of cattle farm and ranch organization and operation, the cow-and-calf type dominates the Polk County

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property kept for tax purposes by Polk County authorities coincide with the numbers owned as stated by the owners themselves. Generally, the numbers in the statements were greater than the numbers in the tax records.

[3] J. O. Bray, "Beef Productivity Increases in the Southeastern United States Since 1920," Food Research Institute Studies, 6(1966) p. 99.

[4] See Table III, P. 64.

[5] For example, as of 1965, the Polk County Tax Assessor's Office values native pasture anywhere from $40 to $100 per acre, and improved pasture anywhere from $100 to $150 per acre. At the same time, it values most cropland at $100 to $150 per acre.

cattle industry.[6] As few Florida soils are considered adequate for grain production and since transportation distances from the major grain producing centers are long and relatively expensive, the Polk County cattle industry has long relied upon grass as its major source of feed. One of the major attributes of the cow-and-calf operation and the steer operation is the need for feeding purposes of large grass acreages. However, the steer operation, if it is to be profitable, requires a high quality animal which has available to it a high quality grass and a relatively insect and disease-free climate. Historically, Polk County and Florida have been lacking in these features: thus it is the cow-and-calf operation which dominates the Polk County cattle industry.[7]

The desired end product in a cow-and-calf program is a heavy calf at weaning time. Maintaining a Florida bred brood herd to drop calves in the early spring, the farmer generally sells the calves at weaning which occurs at approximately eight months of age when the calves weigh between 300 and 450 pounds. Since the program requires the wintering of pregnant cows upon mature grasses relatively low in available nutrients, the cow-and-calf per acre stocking rate must be somewhat lower than that of steer ranches where a large number of animals are purchased in the early spring, fattened on pasture for eight or nine months, and then sold in the fall.[8]

Though cattle raising was introduced to Florida by Ponce de Leon in 1520[9]--thus Florida has been attempting to raise cattle longer than any other state--only during the last thirty-five to forty years has the state's beef cattle industry assumed something approximating its present form. Prior to the late 1930's when certain mineral imbalances and insect-caused diseases were discovered and corrected, the industry relied entirely upon native pasture and the "scrub" cow. This so-called "scrub" cow, a descendant of the original cattle introduced by Ponce de Leon, through many years of adaptation to an environment which included rather unproductive native pastures, nutritional deficiencies and imbalances, and a quite rigorous climate developed into a small, tough, slowly maturing, low grade, relatively unproductive animal that was able to maintain itself moderately well under the prevailing conditions.[10] However, with the introduction of the Brahman bull, an animal well adapted to Florida's humid, subtropical climate, the health of the cattle industry is purported to have shown substantial improvement. It has in fact been asserted that Brahman sires have been responsible for an improvement of fifty per cent in the size of Florida's native cattle.[11] Nevertheless, the average Florida animal is still only about seventy per cent of the size of the average U.S. animal, even though the sale price for Florida animals on a hundred-weight basis has improved from eighty per cent of the national average in 1929 to ninety-five per cent of the national average in 1963.[12]

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[6] The other two types are known as feed-lot operations and steer operations.

[7] Lewis and Cunha, *op. cit.*, pp. 130-148.

[8] *Ibid.*, pp. 148-149.

[9] *Ibid.*, p. 1.

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[10] H. L. Chapman, et. al., Beef Cattle Production on Organic Soils of South Florida, Bull. 662 (Gainesville: Fla. Agric. Exp. Sta., Nov., 1963) pp. 3-5.

[11] Ibid., p. 5.

[12] Florida Crop and Livestock Reporting Service, Florida Agricultural Statistics: 1963 Livestock Summary (Tallahassee: Florida Department of Agriculture, 1964) p. 6 (Mimeographed.)

The amount of beef produced by a cow-and-calf operation is a function of the rate at which the animal will accumulate weight, the animal's final weight in both quantitative and qualitative terms, and the number of animal units[13] with which an acre of pasture can economically be stocked. These variables are in turn some function of the amount and type of forage produced, the reproduction rate, the breed, the age of the dam, and the sex of the calf and its age at weaning. The net revenues of the operation depend upon the cost of feed, housing, health care, and the gross revenues from each animal sold, both calves and cull cows. The cost of feed depends upon the ratio of native pasture to improved pasture, the price of land, the level of taxes, and the cost of dietary supplements.

Though the writer possesses no original data dealing directly with the profitability of the Polk County and Central Florida beef cattle industry, a somewhat hurried comparison of those published materials which are available makes it appear that net returns are quite low. For example, one Florida study experimenting with eight different pasture programs in which forages, fertilization, and irrigation differed between and among the programs showed that only two of the eight programs would result in positive net revenues.[14] The extent to which pasture programs in Polk County resemble the two money-making programs in the experiment is unknown. Similarly, another study in which several realistic combinations of pasture fertilization rates and beef prices were assumed resulted in negative net returns in five of the twenty combinations and such low positive returns in five of the remaining fifteen cases that it seems highly likely the farmer could earn a better return by investing his funds in some other endeavor.[15] Furthermore, a third study made of the actual receipt and expenditure pattern in 1959 for fifteen Florida ranches indicated the highest annual net returns any one of them earned was a negative $2,765. That ranch which placed last had a loss of $22,161.[16]

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[13] One animal unit is equal to 1,000 pounds.

[14] M. Koger, et. al., Beef Production, Soil and Forage Analyses, and Economic Returns from Eight Pasture Programs in North Central Florida, Bull, 631 (Gainesville: Fla. Agric. Exp. Sta., May, 1961), 95 pp.

The preceding of course is far from constituting conclusive evidence that the Polk County beef cattle industry is generally a losing proposition or even a low earnings proposition. Nevertheless, as a glance at Table III makes evident, gross annual returns from beef cattle production only for land in pasture were just slightly over four dollars ($4.26) per acre as late as 1964. And even when woodland used for pasture is deleted, the 1964 per acre gross returns from beef cattle production only were still a very, very modest $6.46.[17] Using the simple capitalization formula of $V=R/r$ and assuming r to be a rather low 5 per cent, gives a per acre land value of only $129.20, even when zero costs are presumed to be associated with beef cattle production.[18] Yet, as we shall later see, Polk County pasture lands--even those devoid of improvements--have been selling for something approximating an average minimum of $200.00 an acre since 1955.[19]

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[15] L. A. Reuss, *et. al.*, *Pangolagrass Pastures for Beef Production in Central Florida: A Method of Determining the Economics of Establishing and Fertilizing Them*, Bull. 585 (Gainesville: Fla. Agric. Exp. Sta., May 1957) 30 pp.

[16] Florida Agricultural Extension Service, *Business Analysis: 1959*, Economic Series 60-12 (Gainesville: Florida Agricultural Extension Service, Nov., 1960), 25 pp. (Mimeographed.)

[17] The national *net* farm land earnings on a per acre basis averaged about $3.70 in 1964. *Cf.* Economic Research Service, *Farm Real Estate Market Developments*, CD-68, U.S. Dept. of Agric. (Wash. D.C.: U.S. Govt. Printing Office, July 1966) p. 21.

Obviously, something in addition to their abilities to provide feed for beef cattle must be contributing to the value of these pasture lands. In a later chapter, Chapter V, an attempt will be made to delineate what some of the additional influences might be.

II. BACKGROUND OF THE POLK COUNTY CITRUS INDUSTRY

Commercial citrus production was first initiated in Polk County in the middle 1890's. Before this time, the center of the Florida citrus industry was about 100 miles to the north of its present center in the Polk County area; however, during the 1894-95 crop season a disastrous series of freezes practically obliterated the industry in this more northern area. Searching for relative safety from cold spells, growers then took note of the rolling hills, plentiful lakes, and deep sandy soils which cover much of Polk County. These attributes, in addition to the more southern location, served to lessen substantially the likelihood of citrus-damaging frosts and freezes. Since its inception in this period, the citrus industry of Polk County, with a 1961-62 value of crop sales of almost $50,000,000 from over 100,000 acres of bearing groves now produces about one-fourth of Florida's citrus output and more than fifteen per cent of the nation's citrus crop.[20] This is a volume of production equal to slightly over three-fourths of the combined citrus production of every other citrus producing area outside the State of Florida.[21] Tables IV and V attempt to give the reader some idea of what these proportions mean in terms of actual returns. Table IV presents information on the arithmetic mean annual gross per acre returns in Polk County while Table V shows the distribution of net per acre returns over five year periods from 1931 through 1964.

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[18] Let V be the present value of a $6.46 per acre annual return, R, stretching into infinity. Then $V = R/r = \$6.46/0.05 = \$129.20$.

[19] See the results of Chapter V for an explanation of the grounds upon which this statement is based.

As is usual in any production relation, there is a whole host of factors which may and usually does affect the output to be obtained from a citrus tree. The most important of those over which the grower can exert absolute control (at a price) are topography, soil type, variety, rootstock, the mean age and distribution of tree ages, cultural practices, and planting systems. Other factors, however, most of which are adverse to the production of citrus, are only partially susceptible to the grower's control. Among these latter factors are such purely natural phenomena as diseases, insects, frosts and freezes, lightning injury, and such partially of natural origin and

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[20] Florida Crop and Livestock Reporting Service, Florida Agricultural Statistics: Citrus Summary, 1962 Issue, (Tallahassee: Florida Dept. of Agric., 1962) pp. 28, 1.

[21] *Ibid.* In 1961-62, total U.S. citrus production outside Florida was 49,000,000 boxes while that of Polk County was 37,500,000 boxes. Thus, in this same crop year, Polk County produced as much citrus as California, which produced only 38,000,000 boxes. When one considers that the typical Florida citrus box is slightly over five per cent larger in terms of the weight it holds than are citrus boxes in the rest of the country, these figures become even more impressive.

TABLE IV

POLK COUNTY COMMERCIAL BEARING CITRUS ACREAGE, VALUE OF SALES, AND GROSS PER ACRE RETURNS

Crop Year	Commercial Bearing[a] Acreage[b]	Value of Production[c]	Gross Per Acre Returns[d]
1947-48	93,505	$23.57	$252
1948-49	95,992	42.69	445
1949-50	99,726	65.52	657
1950-51	103,748	59.14	570
1951-52	108,102	42.06	389
1952-53	108,936	23.46	261
1953-54	107,802	32.07	297
1954-55	116,723	33.77	289
1955-56	108,907	44.20	406
1956-57	110,273	39.52	358
1957-58	105,769	48.30	457
1958-59	106,277	64.95	611
1959-60	111,953	49.46	442
1960-61	105,308	57.32	544
1961-62	107,322	54.58	509
1962-63	101,330	61.41	606
1963-64	101,661	82.84	815

[a] Bearing trees are trees five years old or older.

[b] Calculated on the basis of 65 trees to the acre.

[c] Millions of nonconstant dollars of on-tree value.

[d] Nonconstant dollars.

Source: Florida Crop and Livestock Reporting Service, Florida Agricultural Statistics: Citrus Summaries, (Tallahassee: Florida Dept. of Agric., relevant years).

TABLE V

PERCENTAGE FREQUENCY DISTRIBUTION OF NET PER ACRE CITRUS GROVE RETURNS.

1931 - 1964[a]

Returns[b]	1931-1936	1936-1941	1941-1946	1946-1951	1951-1956	1956-1961	1961-1964
$-400 to -301				0.4	0.1		9.4
-300 to -201				1.7	0.8		
-200 to -101	0.4	0.2	0.2	4.2	2.9	3.4	20.0
-100 to -1	30.9	22.5	1.8	13.8	11.3	8.2	
0 to 99	47.6	51.7	10.2	17.1	15.9	11.8	21.5
100 to 199	14.1	18.0	15.4	16.4	22.9	16.2	
200 to 299	4.7	5.4	17.0	13.3	19.2	14.2	18.2
300 to 399	1.9	1.5	15.1	9.9	10.8	10.9	
400 to 499	0.3	0.5	11.6	7.6	6.6	10.8	9.1
500 to 599	0.1	0.1	9.7	5.0	3.5	7.5	
600 to 699			7.3	4.1	3.2	6.5	7.4
700 to 799		0.1	5.6	2.8	1.6	4.0	
800 to 899			2.5	2.0	0.5	2.9	14.4
900 to 999			1.9	0.8	0.6	0.8	
1000+			1.7	0.9	0.1	2.8	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] Based on a yearly sample of approximately 150 groves of which over ninety per cent were in Polk County or in counties immediately adjacent to Polk County.

[b] Returns net of operating costs

Source: Zach Savage, *Citrus Costs and Returns: Yearly Summaries*, (Gainesville, Univ. of Florida Agric. Extension Service, relevant years).

partially of human origin phenomena as air pollution.[22]

The best sites for citrus production in Florida are considered to be those sites on southern sloping high land close to fairly substantial and deep bodies of water several acres in size.[23] Since cold air is heavier than warm air, the higher sites located on rolling land have adjacent to them, by definition, lower areas into which cold air can drain. But these same sites because of the geologic history of the Polk County area are generally underlain by sandy soils that are very strongly acid in reaction.[24] These sandy soils have both disadvantages and advantages for citrus production. Their advantage lies in the fact that they are generally very well drained,[25] but this advantage is somewhat negated by the fact that these soils "have a very low content of the constituents commonly regarded as plant food."[26] Nevertheless, whether the citrus tree be placed in the most highly desirable or the worst possible location, it will require in order to grow at all a spectrum of fifteen chemical elements, twelve of which must be obtained from the soil. Most Florida soils contain less than half of these elements with those which are present often being there only in inconsequential amounts.[27] As a consequence, citrus production is a sort of "hydroponic" operation relying heavily upon fertilizers to provide the trees with the elements needed to obtain high production of good quality fruit.[28]

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[22] Air pollution is partially of natural origin because the winds which carry or transport the pollutant materials are, for all practical purposes, in no way influenced by man's actions and partially of human origin because the pollutants result from man's decisions about the manner in which he will transform and mix various natural and human factors of production.

[23] J. W. Sites, *et. al.*, *Information to Consider in the Use of Flatwoods and Marshes for Citrus,* Circular S-153A (Gainesville: Fla. Agric. Exp. Sta., Jan. 1964), pp. 22-35.

[24] Earl D. Fowler, *et. al.*, *Soil Survey of Polk County, Fla.*, Bureau of Chemistry and Soils, U. S. Dept. of Agric. Series 1927, No. 39 (Wash., D. C.: U. S. Govt. Printing Office, 1927), pp. 12-33.

[25] Sites, *et. al.*, *op. cit.*, p. 6, assert that trees on these soils produce twice as much fruit as trees on clayey soils which a high pH factor and poor drainage.

[26] Fowler, *et. al.*, *op. cit.*, p. 13.

As with any perennial plant, one of the key factors in citrus production is age. It is commonly thought that until the citrus tree attains an age of forty to fifty years, age and yield are positively related. However, the only detailed study which attempts to provide some indication of this relation that this writer has been able to find is a 1953 study by Kelly.[29] By means of regression techniques he determined that the apparent relation for early oranges was:

$$Y = 0.12724 + 0.35648X - 0.00447X^2,$$

and for late oranges:

$$Y = 1.04847 + 0.41406X - 0.00583X^2,$$

where Y is output per tree in ninety pound boxes, and X is the age of the tree in years. Thus for early oranges, since $dY/dX = 0.35648 - 0.00894X$, the positive relation between age and yeild would cease at about forty years; whereas for late oranges where $dY/dX = 0.41406 - 0.01166X$, the same positive relation would cease at slightly more than thirty-five years of age. These findings, however, appear to be mildly contradicted by the figures set forth in Table VI. These figures are those suggested for use by the State Tax Assessor for the various county tax assessors. In spite of the mild inconsistency between Kelly equations and Table VI, it is apparent that the major increases in yield and value take place during the first twenty years of the tree's life.

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[27] John McPhee, "Oranges", New Yorker, 42 (May 7, 1966) pp. 142-144.

[28] For reasons which will later appear clearly, it is somewhat ironic that the "average" grove each year requires the application of about twenty pounds of phosphoric acid (H_3PO_4) or equivalent per acre.

[29] Bruce W. Kelly, "A Method of Forecasting Citrus Production in the State of Florida," (unpublished Ph.D. disseration, University of Florida, Gainesville, 1953), pp. 4-15.

Surprisingly, the work of Kelly, part of which is set forth in the previous paragraph, appears to be just about the most precise material available on Florida citrus production relations, and it does not take into account the effects of the multiplicity of factors which may influence the posited yield-age relation.[30] Very little usable material is available for the construction of production functions relating yield to such factors as soil qualities and fertilizer use.[31] Without a thorough knowledge of the relevant production relations, it is difficult to determine the degree to which the use of land and associated factors of production for citrus is economic. Nevertheless, on the basis of the preceding material one can reasonably state that citrus production in Polk County appears to be a reasonable economic use of productive factors. Furthermore, given the relatively short time which must pass before a citrus tree yields rather large net returns, it is likely that a substantial portion of Polk County's land area will

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[30] For a highly aggregated study which does consider the effects of such factors as disease, rootstock and variety upon shifts, if any, in the yield age relation, see Chen-Tuan Li, "Input Interactions in Florida Orange Production," (unpublished Ph.D. dissertation, Univ. of Fla., Gainesville, 1962) 83 pp.

[31] That work which has been done is effectively summarized in H. J. Reity, et. al., Recommended Fertilizers and Nutritional Sprays for Citrus, Bull. 536B (Gainesville: Fla. Agric. Exp. Sta., Dec., 1964) 47 pp.

TABLE VI

CITRUS LAND VALUE ACCORDING TO CITRUS AGE AS VIEWED BY FLORIDA TAX ASSESSORS

Grove Age[a]	Average Yield Per Tree[b]	Value Per Acre
1		$ 300
2		300
3		300
4	.9	400
5	1.4	600
6	1.9	800
7	2.3	900
8	2.7	1,100
9	3.1	1,300
10	3.5	1,400
11	3.8	1,600
12	4.1	1,700
13	4.5	1,900
14	4.7	1,900
15	5.0	2,100
16	5.2	2,100
17	5.5	2,300
18	5.7	2,400
19	5.8	2,500
20	6.0	2,500
21	6.1	2,600
22	6.3	2,600
23	6.4	2,700
24	6.6	2,800
25	6.7	2,800
26	6.7	2,800
27	6.8	2,800
28	6.8	2,800
29	6.8	2,800
30	6.9	2,800
31	7.0	2,900
32	7.0	2,900
33	7.0	2,900
34-40	7.1	2,900
41-45	7.2	2,900
46-55	7.3	3,000

[a] Grove age in years.

[b] Yield per tree in ninety pound boxes.

Source: Ray E. Green, Florida Tax Assessor's Guide, (Tallahassee: Fla. State Comptroller's Office, 1963), pp.97c, 97d.

continue to find its highest order of use in the production of citrus. Since most studies indicate that citrus price elasticity of demand is greater than unity and that its income elasticity of demand is positive, increased production which might lower costs of production and market price, and increased consumer disposable income can only result in increased total net revenues for the County's citrus industry.[32]

III. THE BACKGROUND OF POLK COUNTY'S PHOSPHATE INDUSTRY

The comparative advantages which account for the presence of the citrus industry in Polk County and which perhaps account for the presence of the beef cattle industry also go far in explaining the presence of the phosphate fertilizer industry. Located in the midst of one of the world's largest and richest phosphate rock deposits, the Florida phosphate industry has since 1894 supplied over fifty per cent and now supplies over seventy per cent of the nation's annual production of phosphate rock.[33] The value of this rock at the mine alone now has an annual value of over $100,000,000, a reflection of the contribution of the phosphorus elements which it contains to the

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[32] On the price elasticity of demand for citrus see, L. A. Powell, Jr., and Marshall R. Godwin, Economic Relationships Involved in Retailing Citrus Products, Bull. 567 (Gainesville: Fla. Agric. Exp. Sta., Aug. 1955), 87 pp. On the income elasticity of demand for citrus see, Marc A. Nerlove, "Advertising without Supply Control: Some Implications of a Study of the Advertising of Oranges," Journal of Farm Economics, 43 (Aug. 1961), pp. 813-837. Powell and Marshall found the price elasticity to be between -1.1 and -1.8. Nerlove estimated the income elasticity to be 0.67. The writer of this report, employing a single equation, time series, multiple regression model in which there was very serious auto-correlation, obtained the ridiculously high figure for income elasticity of 2.8432. These latter results are not worth reporting in full here.

[33] See Table VII.

TABLE VII

FLORIDA LAND PEBBEL PHOSPHATE ROCK USED FOR THE PRODUCTION OF SIMPLE SUPERPHOSPHATE, PHOSPHORIC ACID, AND TRIPLE-SUPERPHOSPHATE, 1946-64

Year	Simple Superphosphate	Phosphoric Acid	Triple Superphosphate	Florida Value At Mine[b]	As Per Cent of U.S. Value at Mine
1946	3.96	.23	NA	$ 19.87	64.00
1947	4.84	.33	NA	31.98	67.37
1948	5.12	.32	NA	37.07	73.40
1949	4.97	.34	NA	37.34	72.63
1950	5.48	.41	NA	44.43	75.27
1951	5.49	.74	NA	49.19	74.35
1952	5.95	.62	NA	50.48	74.11
1953	4.87	.40	.92	54.50	71.15
1954	4.91	.70	1.04	58.89	72.25
1955	4.62	.60	1.60	57.97	69.93
1956	5.02	.70	1.53	64.35	72.12
1957	4.61	.71	1.81	66.86	72.90
1958	4.42	.59	2.28	66.31	71.48
1959	4.29	.34	3.46	71.77	72.02
1960	4.16	.39	3.67	80.91	70.13
1961	4.32	.38	3.92	88.40	70.38
1962	4.96	.59	4.09	93.67	69.79
1963	4.88	.47	5.03	100.75	71.64
1964	NA	NA	5.29	NA	NA

[a] Millions of long tons.

[b] Millions of non-constant dollars

NA means that data was not available

Source: U.S. Bureau of Mines, Minerals Yearbook, Vol. III, U.S. Dept. of the Interior, (Wash. D. C.: U. S. Govt. Printing Office, relevant years).

productivity of agricultural fertilizers. Though not all of this rock was mined in Polk County, well over ninety per cent of the rock processed in Florida is processed in Polk County or its immediate environs.[34] The value of the outputs of these processing plants is unknown to the writer, but the following table, Table VIII, does serve to provide a general idea of the magnitude of the phosphate industry's impact upon the Polk County economy.

For over fifty years, the Polk County beef cattle, citrus, and phosphate industries practiced peaceful co-existence. Cattle became as fat as one could reasonably expect in the local climate, citrus groves regularly bore their fruit, and the phosphate industry mined its rock, loaded it aboard railway cars or ships and transported it throughout the eastern half of the nation. But in the late 1940's and the early 1950's, the nature of the local phosphate industry underwent drastic change. Coinciding with a period of great expansion and economic buoyancy in the cattle and citrus industries, the character of the national demand for agricultural fertilizers changed and railroad freight rates for bulk commodities were increased throughout the country. These two events resulted in a rapid acceleration of entry of the phosphate rock processing industry into Polk County. The major type of processing carried out by the new entrants was the manufacture of concentrated or triple-superphosphate agricultural fertilizers and

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[34] U. S. Phosphoric Products, Inc., has a processing plant in East Tampa about thirty miles to the west of Polk County. This plant is not considered to be in Polk County's immediate environs. Occidental Corporation is now constructing a plant in the northern part of Florida which will not use to any major extent rock from the central Florida fields.

TABLE VII

SELECTED CHARACTERISTICS OF THE POLK COUNTY PHOSPHATE INDUSTRY[a]

	1958	1959	1960	1961	1962	1963	1964	1965
Number of Employees	5391	5408	5920	5910	6255	6374	6676	7583
Wages and Salaries Paid	25.16	26.54	30.59	32.64	35.63	36.56	40.04	45.18
Paid to railroads	NA	34.83	33.22	32.50	35.00	35.83	36.75	37.95
Paid to electric utilities	8.86	9.25	10.29	10.81	12.29	11.79	13.50	15.23
Paid locally for equipment	10.95	11.23	14.95	17.93	18.03	21.47	28.64	24.67
Paid to local truckers	.69	.82	.93	1.16	1.23	1.48	2.12	2.53
Paid to local contractors	3.10	16.64	20.33	15.76	13.74	10.55	20.82	79.16
Paid for local ad valorem property taxes	2.24	2.32	2.25	2.52	3.21	3.33	3.55	3.51
Total local expenditures	51.00[b]	101.63	112.56	113.32	119.13	121.01	145.12	208.23

TABLE VII (Continued)

[a] All money figures are in millions of non-constant dollars

[b] Excludes money paid to railroads.

NA denotes not available.

Source: Florida Phosphate Council, Lakeland, Fla.

phosphoric acid.

First, commercially manufactured in the early part of this century, triple-superphosphate (TSP) for a long time found little acceptance in the nation's agriculture. Suspicious of its effects upon soils and lacking understanding of its potential positive contributions to crop yields, farmers used minimal quantities of the fertilizer. However, the advent of World War II and its pressures for expanded production of basic foods and fibers caused rapid removal of already depleted phosphorus from the soils of the country's farm belt. This rapid rate of depletion of one of the key plant nutrients, finally brought to the farmers' attention through Federal and state agricultural programs, when joined after the war with various Federal programs attempting to restrict agricultural production and raise commodity prices received by the farmer, is generally felt to have necessitated the application of fertilizers containing higher proportions of plant nutrients in order to maintain total production and maximize individual farm income under the new set of constraints and conditions.[35] Triple superphosphate, which contains approximately fifty per cent available phosphatic nutrients by weight as compared to twenty per cent for so-called simple or unconcentrated superphosphate served to help reduce the economic pressures imposed upon farmers by the new conditions.

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[35] This paragraph and the subsequent paragraph are a very terse summary of selected points from several sources among which are the following: E. L. Baum and S. L. Clement, "The Changing Structure of the Fertilizer Industry in the U.S," Journal of Farm Economics, 40 (Dec. 1958), pp. 1191-1193; Zvi Griliches, "The Demand for Fertilizer: An Economic Interpretation of a Technical Change," Journal of Farm Economics, 40(Aug. 1958), pp. 591-606; Earl O. Heady and Martin H. Yeh, "National and Regional Demand Functions for Fertilizer," Journal of Farm Economics, 41 (May 1959) pp. 332-345; and Jesse W. Markham, The Fertilizer Industry, (Nashville, Tenn.: The Vanderbilt Univ. Press, 1958), pp. 35-206.

Farmers' demands for higher nutrient content phosphatic fertilizers served to shift the manufacturing locations for these fertilizers from a market orientation to a raw material orientation. Since the weight of TSP per unit of P_2O_5 is less than one-half the weight of simple superphosphate, the cost-savings in transportation accruing to a firm locating near its phosphate rock supply are clearly positive. Intensifying this location incentive was an increase after World War II in rail freight charges for bulk commodities. Before 1940, the area in which each of the phosphate rock producing centers[36] had a freight advantage was largely determined by the cost of transporting the phosphate rock. For all but the most distant markets, the minimum cost mode of transportation of phosphatic materials was to ship the phosphate rock to the consuming center and only then to manufacture the fertilizer material. But under bulk commodity freight rates prevailing since 1945, the charge for shipping phosphate rock to the Midwest, that region where the demand for phosphatic nutrients is by far the greatest, has been nearly twice the f.o.b. mine price. Since nearly twice as much rock is required for manufacture of TSP as for simple superphosphate, the cheapest means of supplying a unit of phosphatic plant nutrients to the nation's farmers has been to construct TSP plants squarely in

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[36] Florida, North Carolina, Tennessee, Montana, and Wyoming are the major centers.

TABLE IX

YEAR OF INITIAL PRODUCTION AND PRESENT (1966) RATED ENGINEERING PRODUCTION CAPACITY OF FIRMS PRESENTLY IN THE FLORIDA LAND PEBBLE FIELD

Company and Plant Location	Year[a]	P_2O_5 in Long Tons per Day[b]
V-C Chemical Company, a Division of Socony Mobil Oil (Nichols)	1941	306
Swift and Company (Bartow)	1949	309
Armour Agric. Chemical Company (Bartow)	1949	208
Smith-Douglass Company, Inc. (Plant City)	1954	NA
F. S. Royster Guano Co. (Mulberry)	1955	318
International Minerals & Chemical Corp. (Bartow)	1955	1223
American Cyanamid Co. (Bradley)	1957	354
Davison Chemical Division, W. R. Grace & Co. (Bartow)	1958	1015
Agrico Chemical Co. (Pierce)	1960	526
Armour Agric. Chem. Company (Ft. Meade)	1962	460
Consumers' Cooperative Association (Lakeland)	1965	489
Agrico Chemical Co. (South Pierce)	1965	NA
Central Phosphates, Inc. (Lakeland)	1966	460

Mail Addresses in parentheses.

[a] Florida State Board of Health, Jacksonville, Fla.

[b] Anonymous, "Why Wet Process Stays Afloat," Chemical Week, 99 (July 30, 1966), pp. 44-46. Thousands of short tons of P_2O_5 per year were converted to long tons of P_2O_5 per day by multiplying the former by .8929, dividing by 365 and rounding off to the nearest whole number.

NA denotes not available.

TABLE X

TOTAL RATED ENGINEERING PRODUCTION CAPACITY OF PHOSPHORUS PENTOXIDE OR EQUIVALENT IN THE FLORIDA LAND PEBBLE PHOSPHATE FIELD

Year	P_2O_5 in Long Tons Per Day
1947	25
1949	775
1951	775
1953	775
1955	1,577
1957	1,972
1959	2,235
1961	3,881
1963	4,743
1965	6,944
1966	7,665

Source: Florida State Board of Health.

the middle of the phosphate rock source.[37]

IV. THE EVOLUTION OF FLUORIDES FROM THE PHOSPHATIC FERTILIZER MANUFACTURING PROCESS

The phosphate rock which is principally fluorapatite, a compound of calcium fluoride and tricalcium phosphate, mined from the central Florida land pebble phosphate field contains two chemical constituents of major importance to this study. These two constituents are phosphorus pentoxide (P_2O_5) and Fluorine (F). Florida land pebble phosphate rock contains between thirty and thirty-seven per cent by weight of the first and between three and four per cent by weight of the second.[38] The concentration of the first, P_2O_5, in a form which will make it readily available as a plant food is what the manufacture of phosphatic agricultural fertilizers is all about; the evolution of the second, F, and its possible and sometimes actual emission into the atmosphere as hydrogen fluoride (HF) and silicon tetrafluoride (SiF_4) during the fertilizer manufacturing process is half of what is causing the Polk County air pollution problem.[39] The other half of the problem is, of course, due to the presence of beef cattle and citrus groves in a location where they can be detrimentally affected by fumigations from airborne fluorides.

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[37] It is interesting to note, however, that since the last half of 1965, there has been substantial new TSP plant construction activity in the lower Mississippi Valley, to where the phosphate rock from Florida is transported by ship. The extent to which this activity is due to an increase in the cost of transporting raw sulfur relative to phosphate rock, or to the quite stringent air pollution controls recently adopted by the State of Florida is uncertain. Nevertheless, there seems to be no slowing down of new construction in the central Florida land pebble fields as Tables IX and X attest.

[38] W. L. Hill, "Raw Materials," in U. S. Dept. of Agriculture and Tennessee Valley Authority, Superphosphate: Its History, Chemistry, and Manufacture, (Wash., D. C. : U.S. Govt. Printing Office, Dec. 1964) p.97.

[39] The instability of elemental fluorine is commonly thought to be so great as to have rarely anything more than an extremely transitory existence. When used in this study, therefore, fluorine is to be considered only in its combined state as a fluoride.

The manufacture of phosphatic agricultural fertilizers is based upon the chemical reactions taking place when phosphate rock is treated with sulfuric acid, H_2SO_4, and/or phosphoric acid, H_3PO_4.[40] As previously noted, most phosphate rock from the central Florida land pebble fields contains between thirty and thirty-seven per cent P_2O_5 by weight. Thus a short ton of phosphate rock will contain between 600 and 740 pounds of P_2O_5; however, only about one-tenth or sixty to seventy-four pounds of this phosphorus pentoxide is available as a plant food.[41] But after having been dried and ground, this short ton of phosphate rock when combined with approximately 1,200 pounds of 55° to 60° Baume' sulfuric acid, held in a so-called den or container until the mixture becomes a solid, and then stored for a period ranging from several days to a few weeks, will result in slightly over four hundred pounds of the P_2O_5 becoming available as plant food.

Rather than holding the result of the reaction of sulfuric acid and phosphate rock in a den or container until it hardens so as to obtain so-called simple or normal superphosphate, it is possible, with a somewhat greater quantity of sulfuric acid, to take the reaction's dilute H_3PO_4 and gypsum or calcium sulfate, filter it, and then evaporate it so as to make the H_3PO_4 more concentrated.[42] This strengthened phosphoric acid can then be employed by itself or with sulfuric acid with the phosphoric acid being predominant for the initial chemical treatment of a new quantity of phosphate rock. When the solution brought about by this treatment has its excess water evaporated and is then stored for "curing"[43] for at least a month, the result is a fertilizer generally called triple superphosphate, each short ton of which contrains between eight hundred and one thousand pounds of available P_2O_5. In order to improve the curing, storage, handling, and application qualities of this rather powdery triple superphosphate material. which nevertheless may be full of unhomogeneous lumps, it is often wetted so as to cause its particles to agglomerate. When dried and then cooled, the resultant dense granules of this agglomerated material known as granular triple superphosphate, are extremely hard and resistant to mechanical disintegration.[44]

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[40] The multiplication of the number of units of P_2O_5 by a factor of 1.38 will give the equivalent number of units of H_3PO_4.

[41] The degree to which the P_2O_5 is soluble in a neutral ammonium citrate solution is generally employed as the standard by which P_2O_5 availability is measured.

Figures 2, 3, 4 and 5 show simple flow diagrams for each of the aforementioned processes. These processes constitute the major sources of fluorine evolution in the manufacture of phosphatic fertilizers.[45] The tables attached to each figure are taken from engineering material balance studies of operating plants. Five separate plants are included in the data associated with Figures 2, 3 and 4, while only three individual plants were available for Figure 5 and its associated table. One of the plants in each figure is not in the central Florida land pebble field. Those letters attached to the vertical lines drawn from each process step in each figure indicate the fluorides evolved from the step in question as a percentage of the entire process's total initial fluoride input; while the letters attached to the horizontal lines drawn between process steps indicate as a percentage of the entire process's total initial fluoride input the fluorides not evolved in one step that are passed on to the next step in the sequence.[46] Thus in Figure 3, for example, that plant having a phosphoric acid production process evolving the largest proportion of total initial fluoride input does evolve at the concentration step 52.19% of the fluorides initially fed into the process, leaving 42.87% of these initial fluorides in the end product. On the other hand, that plant having a phosphoric acid manufacturing process evolving the lowest proportion of total initial input fluorides evolved only 19.43% of these initial fluorides at the concentration step, leaving 79.35% of these initial fluorides in the end product.

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[43] The "curing" is simply a continuation of the chemical reaction process between the phosphate rock and the phosphoric acid. In general, the longer the curing time, the greater the quantity of insoluble P_2O_5 which will be converted to soluble form, though the rate of conversion decreases with time.

[44] All the material up to this point in this section was abstracted from two sources: Vincent Sauchelli (ed.), Chemistry and Technology of Fertilizers, (New York: Reinhold Publishing Company, 1960), 692 pp.; and U. S. Department of Agriculture and Tennessee Valley Authority, Superphosphate: Its History, Chemistry, and Manufacture, (Wash., D.C.: U. S. Govt. Printing Office, Dec. 1964) 349 pp.

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[45] Though some ammonium, nitric and simple phosphates are produced in the central Florida land pebble fields, their manufacturing processes are not yet considered to be highly important sources of fluorine evolution. See K. K. Huffstutler and W. E. Starnes, "Sources and Quantities of Fluorides Evolved from the Manufacture of Fertilizer and Related Products," _Journal of the Air Pollution Control Association_, 16 (Dec. 1966) p. 684.

[46] The assumption is made that the air pollutinn control equipment present for nearly every process step in each of the operating plants was neutral with respect to the proportion of the entire process's total initial fluoride input which could be evolved.

The interesting feature of these figures and their associated tables is the often wide discrepancy in the proportion of initial total fluoride inputs evolved as between and among process steps, and most importantly, as between and among plants for individual process steps. Though insufficient information and knowledge was available to permit the construction of detailed systems models of the phosphatic fertilizer production processes, it is important to note that the phosphate companies have available to them means for controlling atmospheric fluoride emissions other than the use of specialized air pollution control equipment, the specialized equipment having a quite minimal impact upon the attributes of the production process.[47] Though included in these other means are the use of phosphate rock having a lesser proportionate fluoride content, or, for a given proportionate fluoride content, the use of less phosphate rock, that alternative which might be particularly applicable (depending on costs) to the Polk County phosphate industry is the elimination or modification of steps in the manufacturing processes themselves.[48] That is the elimination or modification of process steps be varying the magnitudes or the proportions of the process's physical and/or chemical constituents or actually changing these constituents can

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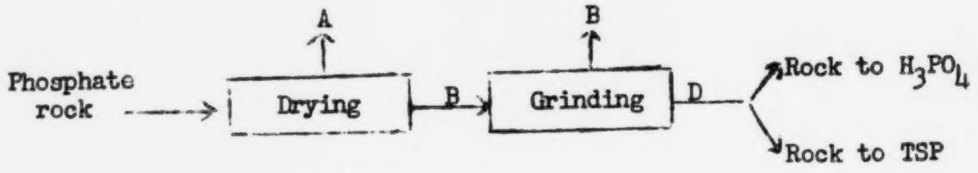
[47] Minimal is used rather cautiously here. The "scrubbers" commonly employed for capturing evolved fluorides in the phosphate industry are necessary to some degree in order to allow employees to work in the plants. Furthermore, many of these scrubbers also provide some assistance in improving process efficiency since while capturing fluorides they also capture phosphorus pentoxide, the very compound to whose availibility the production process is devoted.

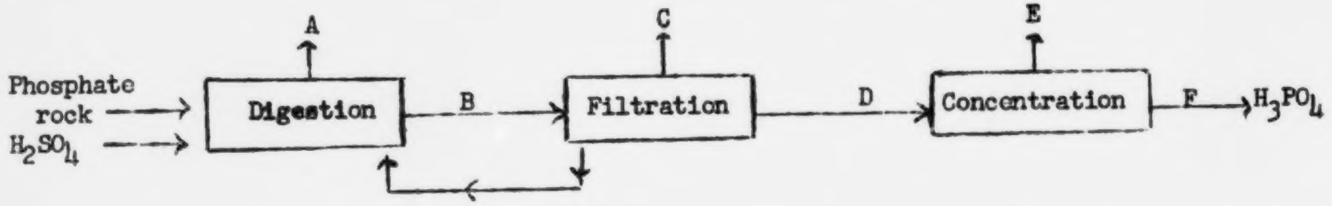
[48] On the proportion of initial total input fluoride which is present in phosphate rock from various locations, see W. L. Hill, op. cit., pp. 97-104. On the proportion of initial total input fluoride which will be evolved for phosphate rock from various locations, see Edward F. Fox, et. al., "Fluorine: Emission and Recovery," in U. S. Dept. of Agriculture and Tennessee Valley Authority, Ibid., p 237.


Phosphate rock
A
Drying
B
B
Grinding
D
Rock to H_3PO_4
Rock to TSP

	A	B	C	D
High Evolution Plant (%)	17.43	82.57	4.22	78.35
Low Evolution Plant (%)	1.88	98.12	1.76	96.36
Mean Evolution Plant (%)	11.49	88.51	2.94	85.57

FIGURE 2

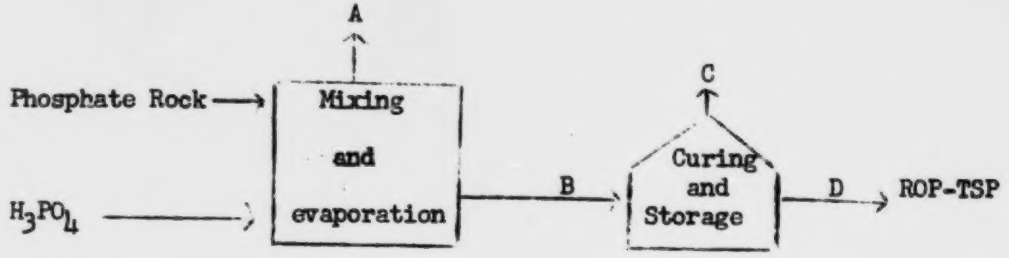
ROCK DRYING AND GRINDING


Phosphate rock
H_2SO_4
A
Digestion
B
C
Filtration
D
E
Concentration
F
H_3PO_4

	A	B	C	D	E	F
High Evolution Plant (%)	4.55	95.45	0.39	95.06	52.19	42.87
Low Evolution Plant (%)	1.06	98.94	0.16	98.78	19.43	79.35
Mean Evolution Plant (%)	2.66	97.34	0.25	97.09	39.67	57.42

FIGURE 3

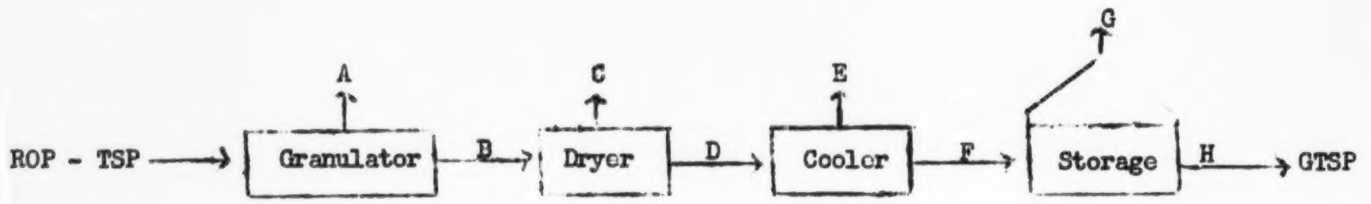
PHOSPHORIC ACID


A
Phosphate Rock
H_3PO_4
Mixing and evaporation
B
C
Curing and Storage
D
ROP-TSP

	A	B	C	D
High Evolution Plant (%)	18.61	81.39	11.43	69.96
Low Evolution Plant (%)	0.61	99.39	4.19	95.20
Mean Evolution Plant (%)	11.42	88.58	6.82	81.76

FIGURE 4

RUN-OF-PILE TRIPLE SUPERPHOSPHATE


ROP - TSP
Granulator
A
B
Dryer
C
D
Cooler
E
F
Storage
G
H
GTSP

	A	B	C	D	E	F	G	H
High Evolution Plant (%)	2.78	97.22	12.93	84.29	6.38	77.91	1.70	76.21
Low Evolution Plant (%)	0.20	99.80	3.79	96.01	1.20	94.81	0.27	94.54
Mean Evolution Plant (%)	1.64	98.36	7.44	90.92	3.85	87.07	1.19	85.88

FIGURE 5

GRANULAR TRIPLE SUPERPHOSPHATE

serve as a substitute for the addition of specialized air pollution control equipment when attempting to reach and/or maintain some reduced volume of atmospheric fluoride emissions.[49]

There is no doubt that many of these process changes are technically--though not necessarily always economically--available. Technically, at least, fluoride retention can be substituted for fluoride recovery. Steps can be taken to evolve the fluorides in earlier stages of the production process where there are lesser volumes of air, thus providing specialized air pollution control equipment with higher and therefore easier to clean concentrations of fluorides. Three-quarters of a pound of sodium hydroxide (NaOH) added to every one hundred pounds of P_2O_5 or equivalent in the curing pile is thought to reduce evolved fluorides by seventy-five per cent, though it is suspected that the reduction in evolved fluorides is acquired only at the cost of a reduction in P_2O_5 availibility. Again, often at some costs in P_2O_5 availibility, fluoride evolution can be affected by varying the concentration and the temperatures of the reagent acids, the degree of acidulation of the phosphate rock, the amount of water vapor present, the grade of the reagent acids, the order of the mixing of the rock, acid, and water, the aggregate surface of the phosphate rock particles and the extent of their surface exposure, the time interval over which the production process takes place, and a host of other complicated and often rather imperfectly understood factors. Certainly, the discrepencies noted in Figures 2, 3, 4 and 5 make it appear that the values assumed by these factors do differ widely from plant to plant in the Florida land pebble phosphate field. At least one phosphatic fertilizer plant capable of producing somewhat over four hundred short tons of P_2O_5 or equivalent per day that was under construction in Florida in early 1967 found it necessary, in order to ensure emission of no more than 240 pounds of fluoride daily, to spend only slightly over one-half of one per cent of its total capital costs upon specialized air pollution control equipment, i.e., air pollution control equipment having absolutely no bearing upon the efficiency of the fertilizer material manufacturing process. Finally, many engineers familiar with the phosphate industry agree that the phosphatic fertilizer plants in the Florida fields were initially designed by mining engineers in the early 1950's on a more or less trial and error basis and as an adjunct to mining operations. Lacking a thorough understanding of the chemical technology involved, these mining engineers supposedly tended to "overdesign" or "underdesign" plants. The result was that very large amounts of fluorine evolution took place, with the "excess" air volumes present in these poorly designed plants causing great air dilution of the evolved fluorides to occur. Many and perhaps most of the plants in operation until the early 1960's were of exactly this initial type. Some of the implications of this phenomenon will be worked out in a later chapter.

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[49] An excellent presentation with an extensive bibliography of some of the responses of fluoride evolution to variations in the constituents or physical and chemical design variables of phosphatic fertilizer production processes is available in Edward J. Fox, et. al., Ibid, pp. 217-250.

V. THE EFFECT OF FLUORIDES UPON CATTLE

Of all agricultural animals beef cattle are among the most susceptible to fluorine toxicosis. Ingesting the toxic material through consumption of forage rather than by respiratory means, the aminal experiences a progressive deterioration in health if continuously exposed to fluoride concentrations in pasture grasses which are by weight greater than approximately forty parts per million.[50] The initial symptoms are often a lack of appetite, losses in body weight, and a mottling of the animal's teeth. If other forage is substituted at this stage for that which is contaminated, the animal will recover, the only deleterious effect having been a temporary reduction in the animal's growth rate. But if substitute forage is not provided, the fluoride due to its affinity for calcium will affect the animal's joints and skeletal structure. Then, as will also happen when the animal ingests fluoride in one very large quantity over a short interval of time, water consumption markedly increases, retching will occur, frequent defacations take place with feces loose and containing blood, and movement becomes unsteady, perhaps with the animal being forced to lie down with its extremities spread. Finally, lumps and boney spurs appear at several points on the skeleton and the animal's joints will stiffen so that it is completely unable to move. Having reached this juncture, the process is irreversible. Self-imposed starvation and finally death conclude it.[51]

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[50] This figure appears in nearly all the literature, but the physical and temporal conditions under which it is accurate have never been completely specified. In fact, few of these conditions are rarely if ever specified. See National Academy of Sciences-National Research Council, The Fluorsis Problem in Livestock Production, Publ. 824 (Wash. D.C.: National Academy of Sciences-National Research Council 1960) p.2.

[51] Ibid. Additional sources employed in preparing this "account" were: Jules S. Cass, "Fluorides: A Critical Review IV," Journal of Occupational Medicine, 34 (Oct. 1961 and Nov. 1961), pp. 471-477, and 527-543; John W. Suttie, et. al.,"The Physiological Effects and the Developmental Symptoms of Fluorosis," Journal of Nutrition, 63 (April 1957), pp. 211-224; and Delbert A. Greenwood, et. al., Fluorosis in Cattle, Special Report 17, (Logan: Utal State Univ. Agricultural Experiment Station, 1964), 36 pp.

The following table, Table XI, lists some of the pasture grass fluoride concentrations that have been found around the Polk County phosphatic fertilizer manufacturing facilities since 1961. As the reader will note, that supposed threshold level of forty parts per million of fluoride by weight which will cause chronic fluorosis has been well exceeded for what appear to be rather extended intervals of time. Thus, if the forty parts per million damage threshold hypothesis is correct, then it is very likely at one time or another that some cattle belonging to the Polk County beef cattle industry have acquired chronic fluorosis.

However, as dramatic as the preceding account might appear--and the writer admits to being guilty of attempting to make it more dramatic by the crude device of leaving out most of the qualifications--very little of the observation of and experimentation with fluorosis which has been performed goes beyond the description of symptoms. Obviously, any level of fluoride ingestion which can result in an animal's death or near starvation has a clear and immediate impact upon the relations relevant to beef cattle production. But the description of readily observable and even not so readily observable symptoms as the fluorine content of various tissues, bones and urine is of little assistance in determining the economic impact of fluorosis. Most literature sources properly emphasize the effects of long-term, low-level fluoride ingestion since most of the fluorosis problems involving atmospheric pollutant fumigations have just such characteristics. However, the symptoms described in this literature provide little if any insight into the effects of fluorosis upon those economic relations which are of major concern to the cattleman: feed conversion efficiency, weight gain, grade, and calf reproduction. In nearly all the

TABLE XI

ARITHMETIC MEAN AND PEAK PASTURE GRASS CONCENTRATIONS[a] OF FLUORIDE IN PARTS PER MILLION BY WEIGHT FOR SAMPLING SITES LOCATED WITHIN ONE MILE RADIUS OF ONE OR MORE POLK COUNTY PHOSPHATE PLANTS

Year	1961		1962		1963		1964[b]	
Plant	Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak
V-C (Pierce)	139.6	962.0	134.9	544.0	87.5	522.0	96.3	231.0
Swift	52.5	139.0	71.5	171.0	65.0	420.0	53.4	151.0
Armour-Bartow	117.0	956.0	136.0	506.0	76.2	463.0	80.7	348.0
Smith-Douglass	87.5	288.0	119.8	648.0	110.1	699.0	84.5	672.0
Royster	114.0	545.0	123.7	295.0	73.0	147.0	80.0	292.0
IMC	203.7	817.0	234.1	1,123.0	232.8	1,212.0	143.5	800.0
American Cyanamid	90.4	316.0	152.5	487.0	185.0	800.0	138.5	363.0
Davison	141.5	379.0	189.0	521.0	100.3	298.0	111.9	437.0
Agrico (Pierce)	127.4	420.0	108.8	344.0	159.7	676.0	178.8	1,493.0
Armour-Ft. Meade	32.7	82.0	62.4	326.0	71.2	514.0	48.0	93.0

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[a] Based on 28 day accumulations of fluorides upon Bahia grass plots mowed each time a sample is taken.

[b] First six months of 1964 only.

Source: Calculated from unpublished Florida State Board of Health data.

investigations only cursory attention or no attention at all has been devoted to these matters. Thus for the most part the assertion that fluorides detrimentally affect beef cattle production is an unproven and, for some relevant relations, even untested hypothesis. Those few investigations which do offer any comments upon these relations do not show evidence of any consistent adverse effects of fluorine, although the majority do find fluorine ingestion and weight accumulation to be inversely related in a statistically significant sense when the animal daily consumes more than 100 parts per million of fluorine by weight over five or six years.[52] Thus one might well argue that there is a tendency for weight and fluorine ingestion to be inversely related, but the "threshold" at which this relation will become effective and the form the relation assumes when the threshold is surpassed remain matters for conjecture.

As for the effects of long-time fluorine ingestion upon reproduction, only one study out of the twelve reported experiments reviewed reported any adverse effect upon reproduction rates for higher than normal levels of fluorine ingestion.[53] However, the investigators themselves admitted openly that the brood cows were subjected to non-fluoride related stresses not ordinarily encountered under even moderately good management practices. No other study showed or at least none reported any statistically significant differences in either calving percentages or the viability rates of calves. One study in fact showed a supposedly statistically significant higher viability rate for calves on high fluorine diets than for calves on low fluorine diets.[54]

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[52] C. S. Hobbs and G. M. Merriman, Fluorosis in Beef Cattle, Bull. 351 (Knoxville: Tennessee Agric. Exp. Sta. 1961) 183 pp.; and G. W. Newall, and H. J. Schmidt, "The Effects of Feeding Fluorine as Sodium Fluoride to Dairy Cattel--A Six Year Study," American Journal of Veterinary Research (April, 1958) pp. 363-376.

[53] Hobbs and Merriman, Ibid., p. 2.

In any cow-and-calf operation, milk production is of no little importance. Again, only a small minority of the twelve studies reported any effects upon milk production. One study stated that there was reason to "suspect" an effect, but could find no valid reason for stating that there was (a strong likelihood) of an effect.[55] But, in contrast to the other studies, one study explicitly stated that consumption of sodium fluoride (NaF) in quantities greater than fifty parts per million by weight will adversely affect milk production.[56]

Of all the factors which contribute to the economic value of a beef animal, grade is that factor which has received the least attention in all the studies reviewed. In fact, the matter of grade is not even mentioned in these studies. Since it is well recognized that it is possible to achieve different grades in a given animal by altering its diet--feeding it more or fewer energy foods--and since it is likely that fluorine may act as an enzyme poison,[57] it seems entirely possible to this writer that fluorine may differentially affect the animals' ability to use various foods and to convert them into a given quantity and quality of meat. In nearly every study where moderate levels of fluorine were ingested the animal's food consumption suffered modest to drastic reductions and at high levels of fluorine ingestion this reduction was associated with though not necessarily related to weight losses. But no attention was given to grade and little attention was given to the question of the rates at which variations in feeds can be substituted for degrees of removal from exposure to opportunities for fluoride ingestion.[58] Nevertheless, it does appear reasonable to assume that dietary fluorine does not affect beef grade independently of its effects upon feed intake but rather through its effects upon feed intake.

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[54] Newall and Schmidt, *op. cit.*, p. 367.

[55] Hobbs and Merriman, *op. cit.*, pp. 2, 21-22, 104 and 107.

[56] John W. Suttie, and P. H. Phillips, "Studies of the Effects of Dietary Sodium Fluoride on Dairy Cows: A Three Year Study on Mature Animals," *Journal of Dairy Science*, 42 (1959), pp. 1063-1069.

[57] Cass, *op. cit.*, p. 473.

Lastly, it does not seem unreasonable, since fluorine has been shown to alter substantially the growth patterns of various types of plants, to suppose that fluorine might also affect pasture grasses in a similar manner.[59] To the extent this is true, a grazing animal would require more pasture in order to obtain a given volume of nutrient material. Although this point might not be of interest to a veterinarian or an animal pathologist, it must be of substantial interest to anyone concerned with the total economic impact of the fluorosis "problem" in the beef cattle industry. But no one seems to have given it any attention.

VI. THE EFFECT OF FLUORIDES UPON CITRUS

The effects of fluorides upon citrus production are even less completely understood than are the effects of fluorides upon beef cattle. Any plant wherever it grows will have to contend with fluorine since that element is found naturally in air, water, and the majority of soil types. The element fluorine is in fact the world's thirteenth most common element.[60] But most fluorides found in water and the soil which would be taken in through a plant's roots are highly water insoluble and are therefore quite unavailable to the plant.[61] In addition, relatively little if any of the airborne fluorides seem to reach the soil. And even when soil fluorides are relatively water soluble and thus available to the tree, they are widely dispersed throughout the tree during the translocation process, thus rarely becoming present in concentrations great enough to do appreciable damage.[62] But these statements about the lack of ability of plants in general and citrus trees in particular to absorb fluorine through their root systems is just as far as most researchers will go with any reasonable degree of certainty. Although it is agreed generally that the leaves of a citrus tree are very efficient absorbers of airborne fluorides, the means by which the leaves carry out the absorption, what happens to the fluorides after they are absorbed, and how one is to distinguish the yellowed appearance of citrus leaves which have been subject to fluorides from the appearance of leaves on a tree which has a zinc or manganese deficiency remain points of much debate, contention, and even legal arguments.[63]

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[58] But several studies have investigated the efficacy of so-called "alleviators" such as the aluminum compounds of chlorine, sulfur, and particularly calcium which serve to neutralize partially the fluorine's toxic effects. Cf. Ibid., pp. 477, 540-543.

[59] See the section immediately following dealing with fluorine damages to citrus for evidence.

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[60] Konrad T. Semrau, "Emission of Fluorides from Industrial Processes--A Review," Air Pollution Control Association Journal, 7 (Aug. 1957)pp.92-93.

[61] Florida Air Pollution Control Commission, "Transcript of Seminar: The effects of Fluorides on Citrus," (Lake Alfred, Fla., Oct. 1, 1964) pp. 2-4. (Mimeographed.)

[62] Ibid.

[63] Ibid., p. 22.

Nevertheless, there appears to be a very definite inverse association between the arithmetic mean concentration of fluorine in parts per million by volume in citrus leaves and the arithmetic mean ambient air concentration of fluorine in parts per billion by volume.[64] Furthermore, the younger the leaf, the greater is its susceptibility to chlorosis (leaf yellowing), to necrosis (tip burn), or to a reduction in its final size in terms of surface area. For example, marked fluorine chlorosis has been observed in immature leaves having fluorine concentrations as small as twenty to thirty parts per million by volume, while mature leaves are often found to have concentrations of over one hundred parts per million by volume with no apparent damages.[65] But no matter how detailed the knowledge about the manner in which and the means by which citrus leaves accumulate fluorides, this knowledge is of little worth other than as a botanical curiosity unless it is understood the extent to which this accumulation affects the leaves' photosynthetic or food manufacturing processes; and, in turn, how the change in these photosynthetic processes affects the quantity and quality of the fruit which the tree produces. It is discouraging to proceed through another literature that endlessly describes symptoms.

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[64] The list of experiments and surveys in which this relation has been shown or asserted is fairly extensive. Some of the more interesting ones are: R. F. Brewer, et. al., "Sorption of Fluorine by Citrus Foliage from Equivalent Solutions of HF, NaF, NH_4F, and H_2SiF_6," Proceedings: American Society for Horticultural Science, 75 (Dec. 1960) pp. 215-219; J. C. Kaudy, et. al., "Contamination of Citrus Foliage from Air Pollution in Major California Citrus Areas," Proceedings: American Society for Horticultural Science, 65 (June 1955), pp. 121-127; and S. W. Wander, and J. J. McBride, Jr., "Chlorosis Produced by Fluorine on Citrus in Florida," Science, 123 (May 25, 1956) pp. 933-934.

[65] C. D. Leonard and H. B. Graves, Jr., "Air Pollution Research," (Lake Alfred, Fla.: Florida Citrus Experiment Station, Aug., 1965) p. 28.

To the best of this writer's knowledge, there exists only one study which has attempted to determine the effects of fluoride absorption upon a citrus leaf's ability to manufacture food, to use the food which it manufactures (respiration), and to produce chlorophyll.[66] Results showed a significant reduction in photosynthetic efficiency, a slight reduction in respiration, and a marked reduction in chlorophyll formation with increased presence of fluoride. This study, however, made no attempt to relate these changes in metabolic processes to the citrus tree's ability to grow fruit.

In all the United States and perhaps the world there are only two completed studies known to this writer dealing directly with the effects of airborne fluorides upon citrus yields.[67] The first of these studies carried out in Florida by Leonard and Graves consisted of a set of experiments over two citrus seasons in which they attempted to relate yield to the fluorine content of spring flush (new leaves appearing in the Spring) citrus leaves. The results of their experiments were summarized in a set of simple regression equations linear in the values of the original variables. In the 1964-65 crop season, an inverse relation existed between the yield of Hamline oranges and Marsh grapefruit and the parts per million by volume of fluorine in the spring flush leaves.[68] What was supposedly the same experiment carried out during the 1965-66 season with the same trees also yielded the aforementioned inverse relation for both citrus varieties. However, the magnitudes of both the intercept terms and the regression coefficients for leaf concentrations had changed. For Hamlin oranges, the negative effect of the fluorine upon yield was less severe in the 1965-66 season than it was in the 1964-65 season; but for Marsh grapefruit the negative effect of the fluorine upon yield was more severe in the 1965-66 season than it was in the 1964-65 season. Thus, assuming that the experiments in the two crop seasons were carried out under the same conditions, the cumulative effect of fluorine between seasons was negative as one would expect for Marsh grapefruit but positive as one would not expect for Hamlin oranges. These rather incosistent results would make it appear either that some important cross-sectional explanatory factor was being excluded from the analysis, and/or that the conditions under which the experiment was conducted differed substantially from one year to the other.

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[66] S. S. Woltz and C. D. Leonard, "Effects of Atmospheric Fluorides Upon Certain Metabolic Processes in Valencia Orange Leaves," Proceedings: Florida State Horticultural Society, 77 (Nov. 1964), pp. 9-15.

[67] R. F. Brewer, et. al., "Some Effects of Hydrogen Fluoride Gas on Bearing Navel Orange Trees," Proceedings: American Society for Horticultural Science, 76 (Dec. 1960), pp. 208-214; and Leonard and Graves, op. cit., 55 pp.

The second set of studies concerning the effects of fluorides upon citrus yields was carried out in southern California by R. F. Brewer and his associates. Brewer's most interesting finding is that citrus trees subjected to three years continuous exposure of fluoride resulting in fluoride concentrations of thirty-five to seventy-five parts per million by weight in young citrus leaves had a fifty-five per cent reduction in fruit yield.[69] This same California group of researchers has in one article stated that the "threshold" level of fluoride concentration in the ambient air at which citrus will be harmed is ten parts per billion by volume.[70] But in another article published in the same journal and by the same group the threshold level is explicitly placed at five parts per billion fluoride by volume in the ambient air.[71] Admittedly, the two articles deal with two different experiments, but there is no attempt to reconcile the seeming disparity. The disparity is by no means of minor importance for the Polk County air pollution problem: levels of ten parts per billion of fluoride in the ambient air have occurred with much less frequency than have levels of five parts per billion.

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[68] Leonard and Graves, Ibid., p. 36-38.

[69] R. F. Brewer, et. al., "Some Effects of Hydrogen Flouride Gas on Bearing Navel Orange Trees," op. cit., pp. 210-212. Brewer implies that yield and fluoride concentration are inversely and causally related, but the manner in which his results are presented shows only a mere association.

In general then, one can only state that the work done with the effects of fluorides upon citrus is quite confusing. The same remark can fairly be made with respect to the effects of fluorides upon beef cattle. Attempts to build air pollution damage estimates for citrus and for beef cattle in any given locale cannot be expected to yield much fruit if they are to start from published material in the physical and biological sciences. As earlier noted, most so-called scientific knowledge of air pollution's effects consists of seemingly endless descriptions of symptoms. Anyone failing to agree with this assertion and the previous discussion of the effects of fluorides upon beef cattle and citrus upon which the assertion is based might try asking his nearest chemist friend (bio or otherwise) the following question: "If the magnitudes and proportions of all other factors which may influence a particular entity are given and if the nature of the relations between and among these factors and the entity are thoroughly understood, can you tell me the magnitude of the effect of a given concentration of a particular pollutant material over a given interval of time upon any economically relevant attribute of that entity?" In nearly every single case the reply will be a somewhat dismayed but nevertheless straightforward "no!" Thus, though most of the studies which have been performed do provide criteria or indicators by which the possible presence of air pollution damages can be determined on a more or less either/or basis, they provide little or no insight into the economically relevant magnitude of damages, either past, present, or future. If the state of the art in the biological sciences is really not such as to allow the investigator to proceed from the cataloguing of symptoms to understanding of the fundamental processes by which pollutants affect an entity's economically relevant attributes, then more attention should perhaps be devoted to determining directly the associations between pollutant concentrations and frequencies and output or yield for various magnitudes and mixes of inputs. Even though the collection of a very large number of studies about symptoms may ultimately provide insight into the fundamental processes whereby a pollutant material affects an entity's economically relevant attributes, greater consideration might be given to determining these fundamental processes by working back from associations between outputs and pollutant concentrations and frequencies. At least the returns from knowing the association would be more immediate than would additional work describing the fluorine content of cattle bones or the color shadings of citrus leaves exposed to fluorides in the ambient air. There is no shortage of facts about the physical and biological aspects of air pollution damages; there is or at least there appears to this writer to be a severe shortage of conceptual constructs that are powerful enough to deal with more than a very few of them.

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[70] R. F. Brewer, et. al., "The Effects of Hydrogen Fluoride Gas on Seven Citrus Varieties," Proceedings: American Society for Horticultural Science, 75 (June, 1960). p. 240.

[71] R. F. Brewer, et. al., "Some Effects of Hydrogen Fluoride Gas on Bearing Navel Orange Trees," op. cit., p. 210.

Given the difficulty or impracticality of attempting to synthesize air pollution damage functions from what appear to be the quite imperfectly understood underlying biological and/or chemical principles, the natural scientist in his experimental or empirical work might consider working more often with input mixes and magnitudes closely corresponding to, if not exactly the same as, those typically found in commercial practice. In most present empirical work, the procedure, apparently because of the desire to and the hope of acquiring insight into underlying biological and/or chemical principles, is to use input configurations which will emphasize differences in the responses of varieties and/or treatments to particular concentrations of air pollutants. This often means that all positive inputs are supplied at levels substantially greater than they would be in commercial practice.[72] Basically, these other inputs are treated as if they are free or at least almost free--a practice the commerical operation would be unable to afford. As a result, the reduction in yield brought about by the application of a given air pollutant concentration and/or

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1 [72] This same point is made in J. C. Headley and J. N. Lewis, *The Pesticide Problem: An Economic Approach to Public Policy,* (Baltimore: The Johns Hopkins Press, 1967) p. 55, and B. R. Davidson and B. R. Martin, "The Relationship Between Yields on Farms and in Experiments," *Australian Journal of Agricultural Economics,* 9 (Dec. 1965) pp. 129-140.

frequency to the magnitude of the experimental positive input mix will be less than when this same frequency and/or concentration is applied to the lesser magnitude of the commerical positive input mix. The reduction in the positive input mix's yield will be relatively high when the ratio of the air pollutant to the mix is high and relatively low when the ratio is low. In short, when only a little of the positive input mix is available a relatively small cutback in air pollutant concentrations and/or frequencies will lead to an increase in output that only a relatively large increase in the positive input mix could have brought about. Similarly, when a large amount of the positive input mix is available, as in most experimental situations, it will take a relatively large increase in air pollutant concentrations and/or frequencies to bring about the reduction in output that a relatively small cutback in the positive input mix could cause. The implication is obvious: if the experimenter wishes to obtain dramatic differences in yields with and without the presence of pollutants, he should employ positive input mixes more closely resembling those employed in commercial practice. Whether experimental designs based upon commerical input mixes and magnitudes will yield as much insight into underlying biological and/or chemical principles is a question to which this writer does not know the answer. Certainly with the use of commercial procedures there might well be some difficulty to overcome confounding of the stresses upon the receptor production relations due to less than biologically ideal mixes and magnitudes of positive inputs and to the air pollutant itself. Nevertheless, an empirical investigation of the net returns involved to practical matters of air pollution control and to fairly esoteric problems of biological systems by placing more emphasis upon the experimental use of commerical input mixes and magnitudes seems a quite worthy project.

Whatever the desirability of having experiments dealing with air pollution damage functions correspond more closely to economic reality, some notion of what these damage functions are in economic reality must be made available. Accordingly, it seems worthwhile to give some attention to the economic nature of air pollution damage functions and to the "best" means of determining them, given the present state of knowledge. The following chapter attempts to do so.

CHAPTER IV

THE ECONOMIC EFFECTS OF AIR POLLUTION AND THEIR MEASUREMENT

Though it is oftentimes clear on an a priori basis that some particular set of circumstances must undergo changes if the fulfillment of the criteria of economic efficiency is to approximated, clarity is often lacking with respect to the magnitudes of the changes which must take place. In order to ascertain these magnitudes, some means of measurement must be available, but before a means of measurement can be employed one must decide that which it is he proposes to measure. In other words, when change in a particular set of circumstances is thought somehow to be desirable, one must be cognizant of what attributes of the set of circumstances he must operate on in order to achieve the desired change. Furthermore, in order to know the extent or degree to which these attributes must be operated on, he must know whether or not the means of measurement he employs actually measure the net economic effects of all these attributes.

In air pollution problems, the objective is to maximize the present value of the difference between the emitter savings and the receptor damages resulting from the release of pollutant materials into the atmosphere. The attainment of this objective in any given set of circumstances requires that one specify an emitter cost-savings function and a receptor damage cost function, and then employ some means of measurement to determine the values the parameters of these functions assume. However, in most air pollution work there appears to be a good deal of confusion or at least lack of recognition of the economic nature of these functions and the relative efficacies of the means by which one might go about determining them. The purpose of this chapter is to demonstrate how these functions must be specified if they are to describe the relevant economic relations, and, given the manner in which these functions must be specified, to suggest a means of measurement which will under many sets of circumstances provide reasonably accurate estimates of the values assumed by the parameters of these relations. For the most part, the argument will be set forth in terms of the receptor damage - cost function, since it is that function about which the writer feels the greatest amount of misunderstanding exists and which generally tends to be the most intractable to easy and accurate estimation. However, many of the arguments are also applicable to the emitter cost-savings function.

I. THE NATURE OF THE FUNCTIONS

Any atmospheric pollution control program having as its objective the optimal allocation over time and space of the air's two value dimensions must necessarily take meteorological variables into consideration. Given a specific volume of emissions over any one interval of time, the actions of the atmosphere govern the length of time and the frequency with which all receptors will be exposed to given concentrations of pollutants. But, since these meteorological variables act impartially as between and among receptors and emitters, maximization over time of the present value of the difference between emitter cost-savings and receptor damage costs requires that the values each relevant meteorological variable is likely to assume through time be known for every possible emitter and receptor site.

As was previously noted, man is presently unable to any significant degree to exercise any real control over these meteorological variables. Thus, although the changeable nature of these meteorological factors will make the emission characteristics which are optimal for any one set of meteorological conditions inappropriate for another set, they are only given data within whose constraints a control system must operate. For each set of meteorological conditions and for each receptor site and emitter site, the optimal values for each of the variables which can be controlled by man must be calculated. For any one site over any one interval of time, a certain probability value will be assigned to the likelihood of occurence of any one set of meteorological conditions. In addition, there will be a certain configuration of emission characteristics which will determine the cost-savings functions for emitters and the damage cost functions for receptors. In theory, therefore, optimal allocation over time of the air's two value dimensions necessitates the calculation, for all possible assumptions as to meteorological conditions over each and every emitter site and receptor site, of the associated set of cost-savings and damage cost functions. By calculating the arithmetic or geometric mean--according to whether the underlying relationships determining these cost-savings and damage cost functions are linear or non-linear--of these functions for all sites a given distance from a specific geographical point or set of points and then summing over all sites, one could determine the mathematical expectation of the difference between emitter cost-savings and receptor damage costs for any one set of emission characteristics. But before attempting this rather ambitious schema, one must know what cost-savings functions and damage cost functions are.

The most obvious and the most immediate effect of air pollution is an increase in the quantity of a given mix of inputs a receptor must use in order to achieve a given level of output; or, what is really saying the same thing, a reduction in the output a receptor can achieve by using a given quantity and mix of inputs. In any case, the receptor's costs per unit of output are increased. If this were the only effect of air pollution upon receptors, one would not need to go beyond inquiring of the physical and natural scientist how much harm pollution will do. The effects of air pollution would be simple, and the measurement of these effects would be simple. Unfortunately, simplicity, whether it be absolute or relative, is rarely if ever a feature of the economic aspects of any air pollution problem.

As was explained in Chapter II, the marginal form of the receptor damage cost function shows the additional compensation receptors would have to receive in order to be indifferent between being subjected to or not being subjected to an additional unit, however measured, of pollutant fumigations. Similarly the marginal form of the emitter cost-savings function shows the additional compensation emitters would have to receive in order to make them indifferent between releasing or not releasing an additional unit of pollutant materials into the atmosphere. The receptor marginal damage cost function and the emitter marginal cost-savings function can, respectively, be regarded as supply functions or demand functions, all according to the distribution of the legal and/or the operative rights to the use of the air resource.

Though it will later be argued that the elements and components necessary for the complete specification of these functions will differ according to the legal and/or the operative distribution of rights to the use of the atmosphere, in this chapter it will be assumed these rights legally belong to the receptors but effectively belong to the emitters. It is thus assumed that the receptor's actions influence the emitter in no way whatsoever and that the receptor is unable to do anything but react meekly to the emitter's decisions to release pollutant materials. This view conforms to that which has been taken by most writers on pollution problems.[1]

Any analyst trying to specify a damage function relating receptor damages to pollutant emissions can pick from several alternative formulations. The major difference in these formulations is in their degree of inclusiveness and generality, or, more succintly, their validity under different sets of circumstances. Certainly, the greater the degree of generality implicit in any formulation, the greater its applicability for both empirical and theoretical work; thus the narrower formulations can be regarded as being distinctly less desirable than the broader and more inclusive formulations.

The first, the narrowest, and unfortunately the most typical of these formulations of damage functions takes a specific mix of fixed and variable inputs as a given and then relates receptor yield to the level, however defined, of pollutant emissions and/or pollutant fumigations. This is equivalent, of course, to regarding all other receptor inputs as fixed with the level of pollutant emissions considered to be the only variable input. Air pollution damages are then thought to follow the traditional economic principle of variable proportions where damages first increase at an increasing rate and then at a decreasing rate. A nice, tidy estimate of total damages is obtained by simply summing or integrating over the marginal damage function. Presumedly, Stage III, the stage of negative returns, of the neoclassical production function does not exist unless the pollutant materials in the ambient air become so concentrated that it becomes worthwhile to mine them.[2]

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[1] Cf. M. Mason Gaffney, "Applying Economic Controls," Bulletin of the Atomic Scientists, 21 (June 1965), pp. 20-25; and Allen V. Kneese, The Economics of Regional Water Quality Management, (Baltimore: The Johns Hopkins Press, 1964) 215 pp.

The key to any critique of this first formulation must be based on the fact that it deals only with the short-run production function and, even worse, since it takes a specific mix of durable and current inputs as a given, deals only with a single point located on a single short-run production function. It assumes in other words that the receptor is utterly incapable of varying his positive input mix in any manner or means. In short, the receptor is at worst regarded as being a catatonic, and at best as finding himself in a situation where the net returns accruing to any and all possible adjustments to air pollution levels are never any greater than zero. At worst, this formulation confuses a stuff with the owner of that stuff, i.e., it confuses a mix of inputs with the owner of that mix of inputs. At best, it requires that the economically rational receptor have no alternative other than resignation to his fate. He is not even allowed to maintain the total physical yield of his output by employing more of the current inputs, nor is he allowed to cut his losses to air pollution by reducing the amounts of the current inputs he employs.

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[2] The clearest statements of this formulation are to be found in: Air Conservation Commission, Air Conservation, (Wash., D.C.: American Association for the Advancement of Science,1965), pp. 288-290; and Ronald Ridker, "Economic Costs of Air Pollution: Studies in Measurement," (unpublished manuscript, Wash., D. C. : U. S. Public Health Service, 1965), pp. 8-14. (Mimeographed.) Though it is far from clear on the matter, that work generally regarded as the seminal piece on the economic aspects of pollution problems seems to employ the same formulation. At least, it never explicitly states what formulation it is employing. See Allen V. Kneese, Ibid. Other examples in the economics literature as well as in the literature of the natural and physical sciences are not at all hard to find.

In spite of the apparently rather limited domain of this first and most simple analytical formulation of the receptor damage function, it does nevertheless provide an opportunity to lend some reasonable degree of precision to the concept of a positive input mixe's pollutant susceptibility. As such, the concept of susceptibility may readily and correctly be regarded as at least somewhat analogous to the well-known concept of adaptability,[3] that attribute of a firm's input mix that permits it to operate with a larger quantity of variable input and thus to obtain significant increases in output at smaller increases in unit costs than would be possible under a less adaptable input mix.

The degree of susceptibility of a given magnitude of a given positive input mix to air pollution damages is directly related to the extent to which the input mixe's marginal physical productivity is reduced by increased pollutant fumigations. Thus in the simple general production function:

$$Y = Y(X,E),$$

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[3] George Stigler, "Production and Distribution in the Short-Run," Journal of Political Economy, 47 (June, 1939), pp. 305-327; and George Stigler, The Theory of Price, (New York: The MacMillan Company, 1966) pp. 129-130.

where Y is total receptor output, X is a given positive input mix, and E is the difference between the potential pollutant fumigations[4] to which the receptor could be subjected and the actual pollutant fumigations to which the receptor is subjected. E is thus the quantity of pollutant fumigations whether measured in terms of frequency and/or intensity, avoided by the receptor over some particular time interval. That is, $E = E_p - E_a$, $(E_p \geq E_a)$, where E_p is potential pollutant fumigations and E_a is actual pollutant fumigations.

When the positive input mix is completely susceptible to pollutant damages, its marginal physical product would fall to zero as soon as actual pollutant fumigations assumed a value greater than zero. That is, for all conceivable values of X, the existence of any value for E_a greater than zero causes X's marginal physical productivity to fall immediately to zero. This case is of course analogous to the phenomenon of fixed proportions where the negative and/or positive production services are strict complements. Here, if one considers E_a to be the negative input, the fixed proportion has a value of infinity.

Given the above, as one moves away from the polar case the inference is easily made that partial susceptibility to pollutant damages involves a reduced rate of fall in the positive input mixe's marginal physical productivity. If the susceptibility of the positive input mix is high, then only relatively few and/or small concentrations of pollutant fumigations need be applied before the marginal physical productivity of the positive input mix approaches zero. Perfect insusceptibility must therefore mean that the technical production environment permits the application of E_a to continue indefinitely without having X's marginal physical product ever assume any value other than that it assumes when E_a never is and is never expected to be any greater than zero.

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[4] As noted in Chapter I, by potential pollutant fumigations are meant those fumigations to which the receptor would be subject in circumstances where the emitters can treat the air's waste disposal abilities as a free good.

The distinctions made above can be clarified with the use of a figure. Figure 6 is intended to point out the identification between perfect insusceptibility and zero reductions in the positive input mixe's marginal physical productivity. In this figure is drawn a series of parallel straight line isoquants whose product interval is constant. This constant product interval shows that it is possible to increase output by moving up the X axis, i.e., by increasing the quantities of the positive input mix, X, used in conjunction with any given quantity of actual pollutant fumigations, E_a. It is also evident that the productivity of X is unaffected by the presence of E_a, for no matter how much E_a is applied, no point on any isoquant shifts with respect to either axis.[5]

The idea of complete susceptibility is also easily conceptualized in Figure 6. All that one need do is imagine each point on the Y_1, Y_2, Y_3 and Y_4 isoquants either flying off the paper or becoming coincidental with the zero output isoquant--the actual pollutant fumigations axis. Similarly, the cases of increasing returns to scale or decreasing returns to scale are readily shown by modifying the figure so that the distances

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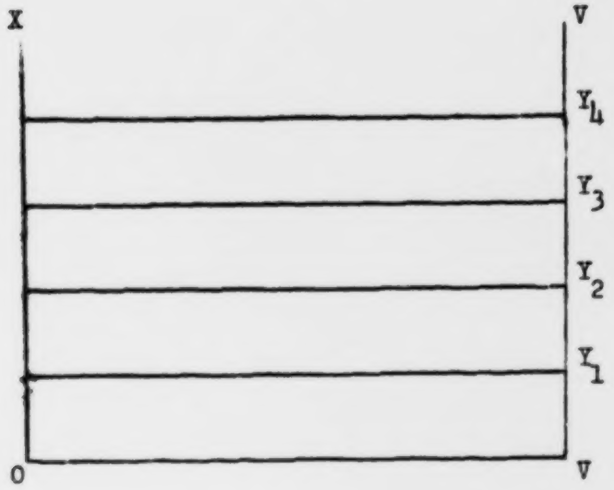
[5] For the moment, the reader is asked to abstract from the line VV.

FIGURE 6

PERFECT INSUSCEPTIBILITY


X
V
Y_4
Y_3
Y_2
Y_1
O
V

$E_a = Y_o$

between isoquants are unequal. For example, in the case of decreasing returns to scale, the isoquants would still be drawn parallel to one another, but, for a given product interval, the distances separating the isoquants would progressively increase as total output was expanded. In this manner, one can readily make the potentially important distinction between the effects of the proportion of positive and negative inputs upon susceptibility and the effects of the magnitude of a given positive input mix upon susceptibility. When increasing returns to scale are operative, the distance between the isoquants becomes closer and closer as one moves out along the X axis. Thus when the positive input mix is perfectly insusceptible to variations in the frequency and/or the intensity of pollutant fumigations, the only phenomenon capable of influencing the positive input mixe's physical productivity is varying returns to scale.

Whether or not varying returns to the scale of the positive input mix exist in any given situation is a strictly empirical question. Nevertheless, the possibility of their existence does serve to warrant extreme caution in attributing differences in the productivities of a given positive input mix present in different magnitudes to whatever variations in pollutant fumigations there may be between and among the various magnitudes. In these latter circumstances, it may not be the increased presence of pollutant fumigations which causes the marginal physical productivity of the positive input mix to turn down as more of it is employed, but rather the downward pressures upon this productivity generated by a changing scale of operations. Though reduced marginal productivity of the positive input mix might occur because the mix is combined with more pollutant fumigations, it might also occur--in spite of increased pollutant fumigations--because each additional unit of the positive input mix must work with more of that mix than previous units were compelled to work with.

The definition of perfect insusceptibility adopted here emphasizes that the marginal physical productivity of the positive input mix fails to decline as pollutant fumigations increase; and this rule is subject only to the modifications imposed by scale effects. By definition, when perfect insusceptibility is present, the positive input mixe's marginal physical product is completely independent of the frequency and/or the intensity of pollutant fumigations. In reality, however, complete susceptibility or perfect insusceptibility are not qualitatively important cases. Instead, that literature of the natural and physical sciences dealing with the impact of pollutant materials on organisms and artifacts generally states that some "threshold" level of pollutant fumigation frequency and/or intensity greater than zero must be reached before any significant effect upon that parameter employed as a damage indicator occurs.

The concept of the threshold and of an instantaneous switch from perfect insusceptibility to complete susceptibility can be presented with the aid of Figure 6. Thus in Figure 6, no point on any isoquant shifts with respect to either axis as one moves from 0 to V on the E_a axis. Over the OV interval, therefore, perfect insusceptibility exists. At and after the pollutant fumigation level V however, the positive input mix, X, becomes completely susceptible to damages from pollutant fumigations because then there is no quantity of the positive input mix which will contribute anything whatsoever to output. In effect, the isoquants disappear after the threshold level of pollutant fumigations, V, has been reached. That is, the marginal product of the positive input mix falls immediately to zero at V, regardless of the quantity of that mix subsequently employed.

More interesting than complete susceptibility or perfect insusceptibility in which the only possible changes in the positive input mixe's marginal physical productivity are either infinity or zero is the situation where the change is somewhere between these two polar values. This more interesting and perhaps typical situation is presented in Figure 7.

Fundamentally, the essence of susceptibility is to be found in the productivity path followed by the positive input mix as more and more of the negative input, actual pollutant fumigations, is combined with it. Rapidly falling productivity of the positive input mix thus implies a high degree of susceptibility of this mix to pollution damages. The isoquants in Figure 7 thus reflect a decreasing marginal rate of substitution[6] of the quantity of pollutant fumigations somehow avoided by the receptor for the quantity of the positive input mix: always assuming E_p to be constant, as the quantity of potential pollutant fumigations avoided increases, that reduction in the positive input mix which will maintain output at a constant level becomes progressively smaller. Similarly, as the quantity employed of the positive input mix becomes larger, that reduction in the quantity of potential pollutant fumigations avoided which will cause output to remain at a constant level becomes progressively smaller. Or, as the quantity of actual pollutant fumigations becomes larger, the additional quantity of the positive input mix which must be provided in order to maintain output at a constant level becomes progressively larger.

---

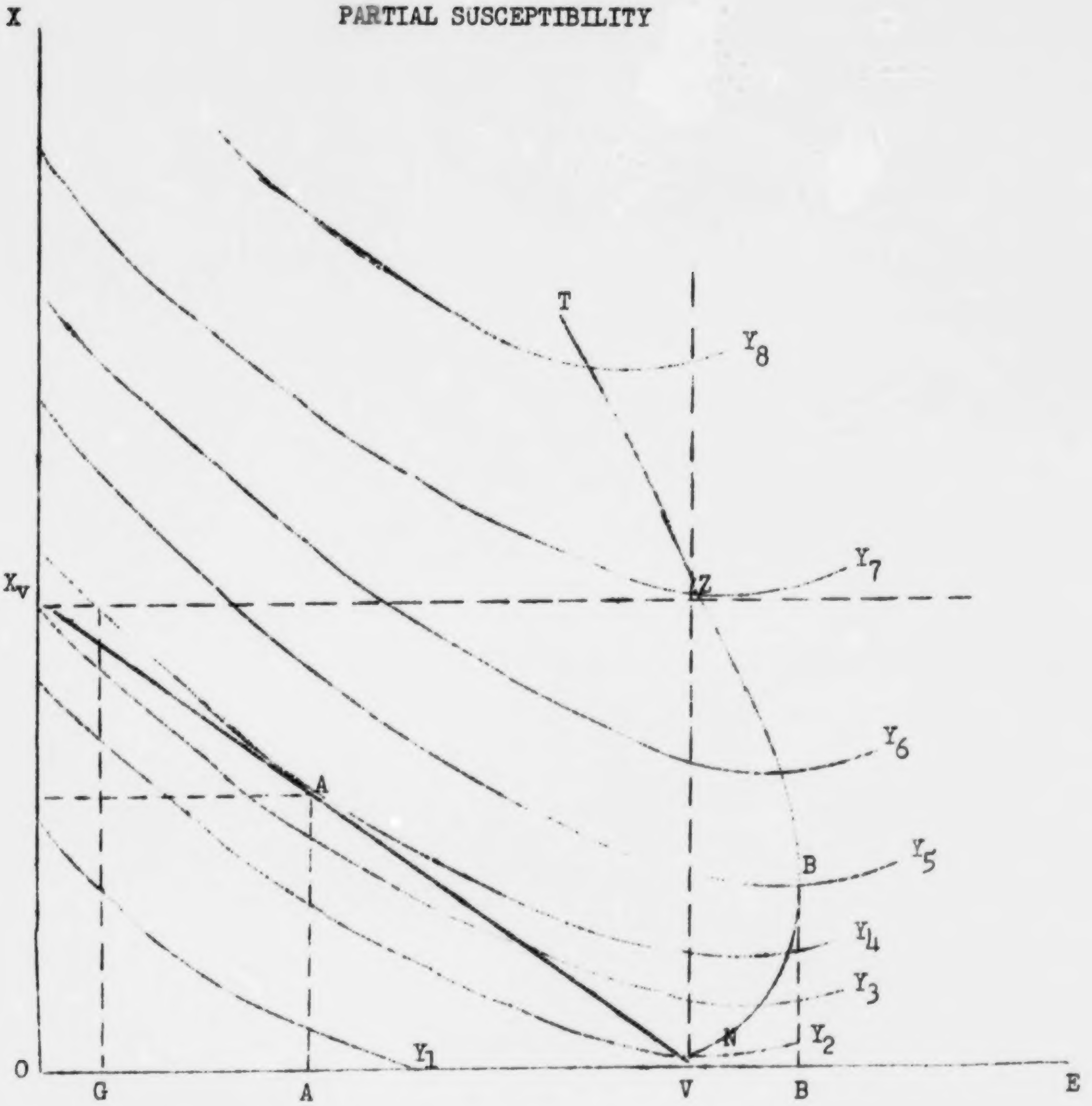
[6] The marginal rate of substitution of the quantity, E, of pollutant fumigations avoided by the receptor for the positive input mix is equal to the ratio of the marginal physical product of E to the marginal physical product of X, where E's marginal physical product is the change in X's total physical product per unit change in E.

In Figure 7, actual pollutant fumigations have been replaced by the potential pollutant fumigations avoided by the receptor, the difference between potential and actual pollutant fumigations. The isoquants are allowed to intersect the vertical or X axis because the receptor could conceivably produce his output even when potential pollutant fumigations are equal to actual pollutant fumigations. That is, some output could be produced without the presence of E, though no output could be produced without the presence of X.

If the receptor is unable to exert any control over the level of actual pollutant fumigations to which he will be subject and if the only choice open to him concerns the quantity of the positive input mix he can select, then he would select that quantity which enables him to reach the highest possible isoquant--given his budget constraint. Thus in Figure 7, if V is the quantity of potential pollutant fumigations the emitter is allowed to avoid, the receptor would spend all of his available funds on the purchase of X. If W. signifies the funds available to the receptor and if P_x is the unit price of X, the receptor will purchase $X/P_x = X_v$ units of X. This purchase would enable him to reach the highest possible isoquant (level of output) he can reach, given his dual constraint of budget and the actual pollutant fumigations over which he can exert no control. This highest attainable output is

FIGURE 7

PARTIAL SUSCEPTIBILITY


X
T
Y_8
Y_7
Z
X_v
Y_6
A
B
Y_5
Y_4
Y_3
N
Y_2
Y_1
0
G
A
V
B
E

shown by the point Z at the intersection of the lines drawn from X_v and V to the Y_7 isoquant. The receptor, since he is unable to do anything about the actual level of pollutant fumigations to which he will be subject, simply attempts to purchase and use as best he can the positive input mix.[7] The very best he can do under the circumstances is to reach the Y_7 isoquant.

It is not entirely inconceivable that the receptor will be able to influence by pecuniary, legal and/or political means the level of pollutant fumigations to which he will be subject.[8] In this case, he has to decide just how to allocate his budget between the purchase of the positive input mix and the securing of some positive degree of control over pollutant fumigations. That is, he has to decide how much of his limited budget to spend on the positive input mix and how much to spend on the provision of some degree of freedom from pollutant fumigations.

The problem the receptor faces when faced with the necessity of choosing between more freedom from actual pollutant fumigations and a lesser use of the positive input mix--and vice versa-- is also shown in Figure 7. The line X_vAV, showing the various maximum combinations of the positive input mix and freedom from actual pollutant fumigations the receptor might feasibly with his budget obtain, is the receptor's budget constraint line. The slope of this budget constraint line is the ratio of the receptor's unit cost of securing freedom from actual pollutant fumigations to the unit price of the positive input mix. The budget constraint line thus shows the rate at which the pecuniary, legal and political realities will allow the receptor to substitute freedom from pollutant fumigations for the positive input mix. As is well known, the receptor will be maximizing his net revenues when he selects that combination of the positive input mix and freedom from pollutant fumigations given by the tangency of the budget constraint line and an isoquant. At this point of tangency--given by A in Figure 7--the rate at which the pecuniary, legal and political realities will allow the receptor to substitute freedom from actual pollutant fumigations for the positive input mix is equal to the rate at which the existing (or expected) technology allows the receptor to carry out this substitution. The receptor cannot reach a level of output higher than that given by this tangency condition.

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[7] All this assumes--with the sole exception perhaps of the non-existent market for the right to avoid pollutant fumigations--that the receptor operates in a perfectly competitive input and output market.

[8] See Chapter V for some examples.

One will note that in Figure 7 the highest level of output the receptor can achieve when operating under the single constraint of a given budget is less than when he operates under the dual constraint of a given budget and a given level of freedom from pollutant fumigations. The reason is, of course, that in the latter or dual constraint case the receptor costlessly obtained that freedom from actual pollutant fumigations given by V; whereas in the former or single constraint case the receptor has to choose between having X or E. Given $X_V = W/P_X$, the fact nevertheless remains that any level of freedom from actual pollutant fumigations greater than A provided for the receptor is greater than the level the receptor would voluntarily select for himself. From the receptor's point of view, therefore, the costless provision to him of OV units of freedom from actual pollutant fumigations provides him with three additional units of output, the difference between Y_7 and Y_4. If, however, the level of freedom from actual pollutant fumigations costlessly provided the receptor is less than OG, the receptor would involuntarily have to produce less output than he actually considers optimal.

To continue with Figure 7, even if the level of freedom from actual pollutant fumigations with which the receptor is provided or that his budget permits him to purchase voluntarily is actually equal to potential pollutant fumigations, E_p, the receptor would never desire more than the level indicated by B of E. The line NBT, of which B is the outermost point, is the so-called "ridge line" of the isoquant map. It would always be irrational[9] for the receptor to proceed beyond the ridge line because he could obtain the same quantity of output using less of at least one input and no more of any other input.[10]

For any line such as X_vZ drawn at a ninety degree angle to the X axis, the longer this line between the X axis and the ridge line, the greater the indicated susceptibility to air pollution damages of the receptor's positive input mix. This is merely a diagrammatic way of saying that the greater the pollution damage susceptibility of a given quantity of a positive input mix, the greater must be the difference between potential and actual emissions (the greater must be E)

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[9] Perfect physical and temporal divisibility is assumed here. See E. J. Mishan and G. H. Borts, "Exploring the 'Uneconomic' Region of the Production Function," Review of Economic Studies, 29 (Oct. 1962) pp. 300-312, for a case in which such behavior cannot be considered economically irrational.

[10] In Figure 7, the X axis constitutes the second ridge line.

in order to prevent reductions in the marginal physical product of the positive input mix. A line segment X_vZ of length $E \rightarrow E_p$ would therefore imply that the quantity in question of the positive input mix is susceptible to pollution damages for all positive pollutant fumigation levels; while a line segment consisting only of a point such as X_v on the X axis would indicate that the quantity of the positive input mix under consideration possessed perfect insusceptibility to pollutant fumigation damages. In the former case, nothing other than absolute air "purity" would serve to maintain absolutely X_v's marginal physical productivity; while in the latter case, the "purity" of the air makes absolutely no difference to X's marginal physical productivity. To perceive this, one must remember that E's marginal physical product is decreasing as one moves down any single isoquant. At the ridge line, this marginal physical product is zero; that is, further increases in E will not contribute anything to X's productivity. If the level of E at which E's marginal physical product becomes zero happens to coincide with the level of E at which $E = E_p$, then the quantity of the input mix under consideration is highly susceptible to damages from pollutant fumigations.[11] The greater the degree of convexity of the isoquants, the less susceptible to pollution damages is the positive input mix.

As developed here, the term susceptibility to pollution damages refers to the distance along a so-called short-run expansion path such as X_vZB in Figure 7. However, since a positive input mixe's pollution damage susceptibility may clearly vary from one combination of X and E to another, the construction of some measure enabling one to compare the realtive susceptibilities of various combinations has interest. Ideally, the measure would also serve as a standard by means of which one might compare the susceptibilities of various positive input mixes and magnitudes to various types of pollutants. One widely employed simple and useful standard in economics which is independent of physical and/or economic units of measure is the elasticity concept. The purpose of the measure would be to have a basis for comparison of the relative contribution of changes in E for various types of pollutants to various input mixes' total physical productivity. In short, the measure would weigh the responsiveness of the total physical productivities of various magnitudes of various positive input mixes to changes in the levels of sundry pollutant fumigations. A measure which consists of the proportionate change in the marginal physical product of E relative to the proportionate change in E itself has all the desirable characteristics of the typical elasticity measure. That is:

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[11] The area enclosed by the ridge lines (the X axis and the locus of points for which receptor freedom from pollutant fumigation has zero marginal physical productivity) can contract and expand in response to changes in the output interval over which decreasing and increasing returns to scale occur as well as in response to changes in pollutant damage susceptibility.

$$(2)\quad S = \frac{\Delta MPP_E}{MPP_E} \bigg/ \frac{\Delta E}{E},$$

or in continuous terms when other inputs enter the production function:

$$(3)\quad S = \frac{\partial^2 Y}{\partial E^2}\, E \bigg/ \frac{\partial Y}{\partial E},$$

where S is the elasticity of air pollution damage susceptibility and MPP_E is the marginal physical product of avoiding actual pollutant fumigations. The definition says, in effect, that an "elasticity of susceptibility" coefficient is provided by considering the change in E's marginal physical product relative to the change in E. Thus, if within the ridge lines, an increase in the receptor's freedom from pollutant fumigations provides no increase in the positive input mixe's total physical productivity, then the value assumed by the elasticity coefficient will be zero, indicating that at least for the region in question perfect insusceptibility is the case. Whenever less than perfect susceptibility occurs the elasticity of susceptibility coefficient will assume a positive sign because then increases in the positive input mixe's total physical product and increases in the freedom from pollutant fumigations are directly related. It also follows, of course, that increasing positive magnitudes denote increasing susceptibility. In the limiting case, an infinitesimal change in freedom from pollutant fumigations causes a large proportionate change in the positive input mixe's marginal physical product and the coefficient for the elasticity of susceptibility approaches positive infinity, or complete susceptibility.[12]

That formulation of the damage function can be improved upon which requires that the receptor stick through thick and thin with a single input mix--or even with a given magnitude of a single input mix. One distinct improvement of the simplistic formulation is that which allows the receptor to substitute inputs less susceptible to pollution damages for those inputs more susceptible to pollution damages: to substitute inputs having a lesser elasticity of susceptibility for those having a greater elasticity of susceptibility.[13] Assume the receptor employs two positive inputs, X_1 and X_2, the second of which is some bundle of inputs whose elasticity of susceptibility to air pollution damages is relatively low. The first input bundle, X_1, is assumed to be highly susceptible to the effects of air pollution, i.e., its physical productivity is seriously and negatively affected by air pollutant fumigations. Let YY in Figure 8 be the unit isoquant for the receptor when he is not subject to the negative impact of air pollutant fumigations. As the level of pollutant fumigations, however defined, to which the receptor is subject becomes greater than that positive level at which receptor damages are initiated, the unit isoquant YY shifts away from the origin because more inputs are required in order to maintain output at a constant level. The unit isoquant thus shifts to a new position, say Y*Y*. At any set of relative factor prices for X_1 and X_2 the receptor's unit costs of production in equilibrium have increased. This increase is given by the dollar equivalent of the distance ku on the X_2 axis plus the dollar equivalent of the distance vw on the X_1 axis.

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[12] If potential pollutant fumigations do not appear as a relevant decision variable to either emitters or receptors or if these potential fumigations are treated as a constant, then actual pollutant fumigations, E_a, can readily be substituted for potential pollutant fumigations avoided, E. In the case of this substitution, however, the sign of the coefficient for the elasticity of substitution would change, for there is an inverse relation between the positive input mixe's total physical productivity and the quantity of actual pollutant fumigations. Thus the nearer the coefficient for the elasticity of susceptibility to negative infinity, the greater the degree of susceptibility to air pollution damages of the magnitude in question of the positive input mix.

As the receptor's unit costs of production increase in equilibrium in response to reductions in output at constant input prices, two effects are discernable: an output effect and a substitution effect. The output

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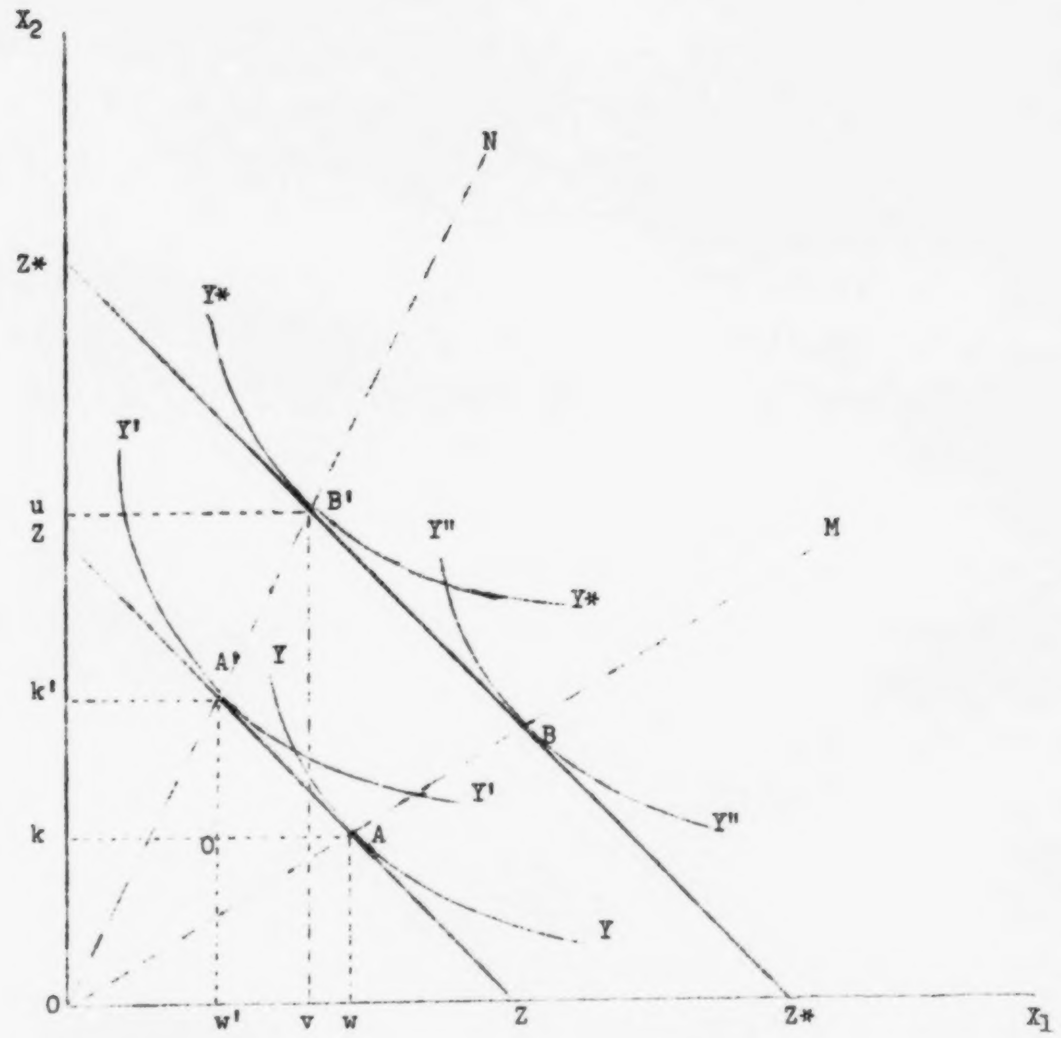
[13] Charles R. Plott in his "Externalities and Corrective Taxes," Economica, 33 (Feb. 1966), pp. 84-87, recognizes the possibility of input substitution in his formulation of the emitter cost-savings function. Plott's recognition of the possibility of input substitution is rare, if not unique, in the conceptual economics literature dealing with air and water pollution.

FIGURE 8

INPUT SUBSTITUTION


X2
N
Z*
Y*
Y'
u
Z
B'
Y"
M
Y*
A'
Y
k'
B
Y'
k
O
A
Y"
Y
0
w'
v
w
Z
Z*
X1

effect, to which sole attention was devoted in the pages dealing with input susceptibility to pollutant fumigations, implies that the output per unit of either input, X_1 and X_2, is reduced; and the substitution effect implies that the input whose physical productivity is less affected by pollutant fumigations, X_2, will be substituted for X_1. Given that the receptor was operating at an optimal scale before the advent of pollutant fumigations, the output effect implies that unit costs of production will increase directly with the extent to which there were diseconomies of scale associated with the receptor's expansion function before the advent of pollutant fumigations. That is, the greater the diseconomies of scale associated with the receptor's scale function before the advent of pollutant fumigations, the greater the increase in the receptor's unit costs of production with the advent of air pollution. In terms of Figure 7, the existence of economies or diseconomies of scale for the positive input mix, X, is given by the interval between isoquants for any given level of potential pollutant fumigations avoided. The substitution effect implies that the amount of X_2 used after the advent of air pollution relative to the amount of X_1 used will vary directly with the extent to which the pollution causes (at the optimal scale of production) the rate of technical substitution between X_1 and X_2 to change. That is, the pollutant fumigations cause the rate at which X_2 must be substituted for any given quantity of X_1 in order to maintain any given level of output to increase. Thus the greater the extent to which the receptor can substitute X_2 for X_1, at the optimal scale of production, the less the increase in the receptor's unit costs of production.[14]

The pure substitution effect of air pollutant fumigations upon a receptor is an effect resulting from the technical or physical substitution of one input bundle for another without any change in the receptor's unit costs of production. For example, if the unit isoquant in Figure 8 shifts from YY to Y*Y* because of pollutant fumigations, the substitution effect of this shift is given by the movement of the unit isoquant from YY to Y'Y'. That input bundle less susceptible to pollution damages, X_2, has been substituted for the input bundle more susceptible to pollution damages, X_1, but the receptor's unit costs of production have remained unchanged.[15]

The pure output effect of air pollution upon a receptor is an effect resulting in an increase in the receptor's unit costs of production at constant input and output prices and at a constant ratio of employment of the X_2 bundle to the X_1 bundle. In Figure 8, the pure output effect of air pollutant fumigations is represented by a shift of the unit isoquant YY to a new position Y"Y", where at the same factor prices the isocost line is represented by Z*Z*, and, as the scale line drawn from the origin shows, the ratio of employment of X_2 relative to X_1 is unchanged.

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[14] The isoquant Y*Y* and Y'Y' in Figure 8 can be viewed as representing an X_2 - intensive production process, while the isoquants YY and Y"Y" are viewed as representing X_1 - intensive production process.

[15] If there is a third input present, X_3, which is in some sense fixed, the substitution of X_2 for X_1 without any increase in unit costs of production implies that the fixed input has some nonzero degree of flexibility. This is because by selecting X_3, the receptor did not commit himself to combining only X_1 with X_3 over the fixed input's economic life. For more on the flexibility concept, see Chapter VI.

From the preceding, it is evident that the net impact of air pollutant fumigations upon the receptor's unit costs of production will be a combination of the two effects, the output effect and the substitution effect. Given the demand conditions for the receptor's output, the two effects tend to pull in opposite directions, for the greater the output effect the greater the increase in the receptor's unit costs of production, and the greater the substitution effect, the less the increase in the receptor's unit costs of production. In other words, the output effect and the receptor's unit costs of production vary directly, while the substitution effect and the receptor's unit costs of production vary inversely. Thus one can fairly conclude that the less the possibility of substitution of another less susceptible input bundle for an input bundle which can have reductions in its physical productivity caused by air pollutant fumigations, the less the likelihood of error in positing a simple functional relation between receptor output and emission levels apart from any explicit consideration of the receptor input mix which is involved. Therefore when trying to characterize and specify the receptor damage function for an agricultural crop to which different types, widely varying, and highly divisible quantities of current inputs can be applied, positing a simple, direct functional relation between receptor damages and emission levels is a highly questionable procedure; but in cases where opportunities for current input substitution and variation are very slight--as would be the case for example with a building and its stonework--the dangers inherent in assuming the aforementioned direct functional relation are relatively minor. In fact, given the costs of acquiring, collating, and analyzing information, these dangers may be nonexistent.

But even though a receptor may substantially lessen the reduction he suffers in the quantity of his output and in his unit costs of production by the expedient of input substitution, any fully specified air pollution damage function must also give attention to the effect of air pollution upon output quality. Though the receptor in Figure 8 can move from YY to Y'Y' finally using w' of X_1 and k' of X_2 rather than w of X_1 and k of X_2 with no change in the quantity of his output nor in his unit costs of production, some explanation other than chance or random walks must be provided for his initial selection of wX_1 and kX_2. That is, X_2 might even be a perfect substitute for X_1 in quantity terms, but when viewed in quantity and in quality terms it can become a less than perfect substitute for X_1. Thus the receptor may still suffer pecuniary losses from air pollution because the quality of his unaffected quantity of output is reduced. In other words, even though his total cost function may be completely unaffected by the pollution because of the availability of input substitutes, the pollutant fumigations cause his total revenue function to shift downward, thus giving him a smaller net revenue with than without pollutant fumigations for every unit of output he produces. One must remember that the marginal value productivity function for any input contains a revenue element as well as a physical productivity element.

Certainly, examples of air pollution reducing the quality or the quality and the quantity of an input are not at all unusual. In the western portion of Hillsborough County, Florida, atmospheric fluorides from a single phosphoric acid and triple-superphosphate fertilizer plant have reduced farmers' yields of gladiolus, and in addition, by giving the gladiolus' leaves a necrotic appearance have reduced the quality and therefore the saleability of much of that yield which is obtained.[16] Many common gaseous forms of air pollutants reduce the tensile strengths of various fibers[17] and adversely affect the technical efficiency of electrical contacts.[18] There is some suspicion that exposure of on-tree citrus fruit to atmospheric fluorides may tend to reduce its vitamin C content.[19] No one has investigated the effects of fluorides upon the grades of beef cattle, but it does not seem unreasonable to suspect the existence of a detrimental quality effect.[20]

The key feature of air pollution's effect upon the attributes of an output is the reduction which it causes in the services or utilities the output is capable of providing for those who at any given price will use or consume some of it. Though there appears to be some degree of interdependence between the output quality dimension and the output quantity dimension since air pollution often causes a reduction in both, this is no adequate reason for thinking that the multiplication of one of these dimensions by a constant factor will always provide an accurate estimate of the value assumed by the other dimension. Thus the assumption that the reduction in the quality of yield is some constant proportion of the reduction in the quantity of yield does not constitute much of an improvement over the utter neglect of the quality dimension. One formulation seems no more arbitrary than does the other formulation. It is in fact entirely possible that every damage function which relates quantity of yield to the level of air pollution is actually made up of several different yield qualities. In air pollution problems, the output itself is as likely to be a variable as is the quantity of the output. Thus, ideally, for every given product quantity, a damage function which relates output quality to the level of air pollution must be constructed, just as every given product quality requires the construction of a damage function relating product quantity to the level of air pollution.[21]

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[16] D. C. McCune, et. al., "Effect of Mineral Nutrition on the Growth and Sensitivity of Gladiolus to Hydrogen Fluoride," Contributions of the Boyce Thompson Institute, 23 (Oct.-Dec. 1966), pp. 295-299; and J. J. Schueneman, et. al., A Report on Florida's Air Resources, (Jacksonville: Florida State Board of Health, 1961), p. 24.

[17] Z. Travnicek, "Effects of Air Pollution on Textiles, Especially Synthetic Fibers," International Clean Air Congress: Proceedings, Vol. 1 (London, England, Oct. 1966) pp. 224-226.

[18] M. Kobayaski, "Effect of Air Pollution and Its Prevention on International Telecommunications Systems," Clean Air, 3 (March 1966) pp. 45-51.

[19] What little evidence there is has failed to substantiate this suspicion however. Cf. C. D. Leonard and H. B. Graves, Jr., "Air Pollution Research," (Lake Alfred, Fla.: Florida Citrus Experiment Station, Aug. 1965), p. 23. (Mimeographed.)

[20] Cf. pp. 97-103 of Chapter III in this essay.

Consider a receptor for whom we can shake out the pure substitution effect of air pollution from the pure output effect of air pollution. We are thus able to hold the receptor's unit costs of production constant. Returning again to Figure 8, assume that the movement of the isoquant YY along the isocost function from A to A' resulted in a measureable reduction in the quality of Y from Q to Q'. Q is thus the quality of the receptor output when the receptor is not subject to air pollutant fumigations, and Q' is the quality of the receptor output after that increase in the level of air pollutant fumigations, which, if the receptor was concerned only with the quantity of his output, would result in the pure substitution effect represented by AA'.

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[21] Cf. Edward H. Chamberlain, The Theory of Monopolistic Competition, 7th ed. (Cambridge, Mass.: Harvard Univ. Press, 1956) pp. 78-81.

It is assumed then that there are only two possible qualities of Y, Q and Q'.[22] The greater the level of air pollutant fumigations to which the receptor is subject, the greater the proportion of the given quantity of output which is of quality Q', and the less which is of quality Q. Or, saying the same thing in a slightly different manner, the substitution of X_2 for X_1 following from the damaging air pollutant fumigations results in an increase in the proportion of the output which is of quality Q' and reductions in the proportion of output which is of quality Q.[23] If the quality productivity of X_2 was initially the equivalent of X_1's, then, given equal quantity productivities and equal input prices, the receptor could before the advent of air pollutant

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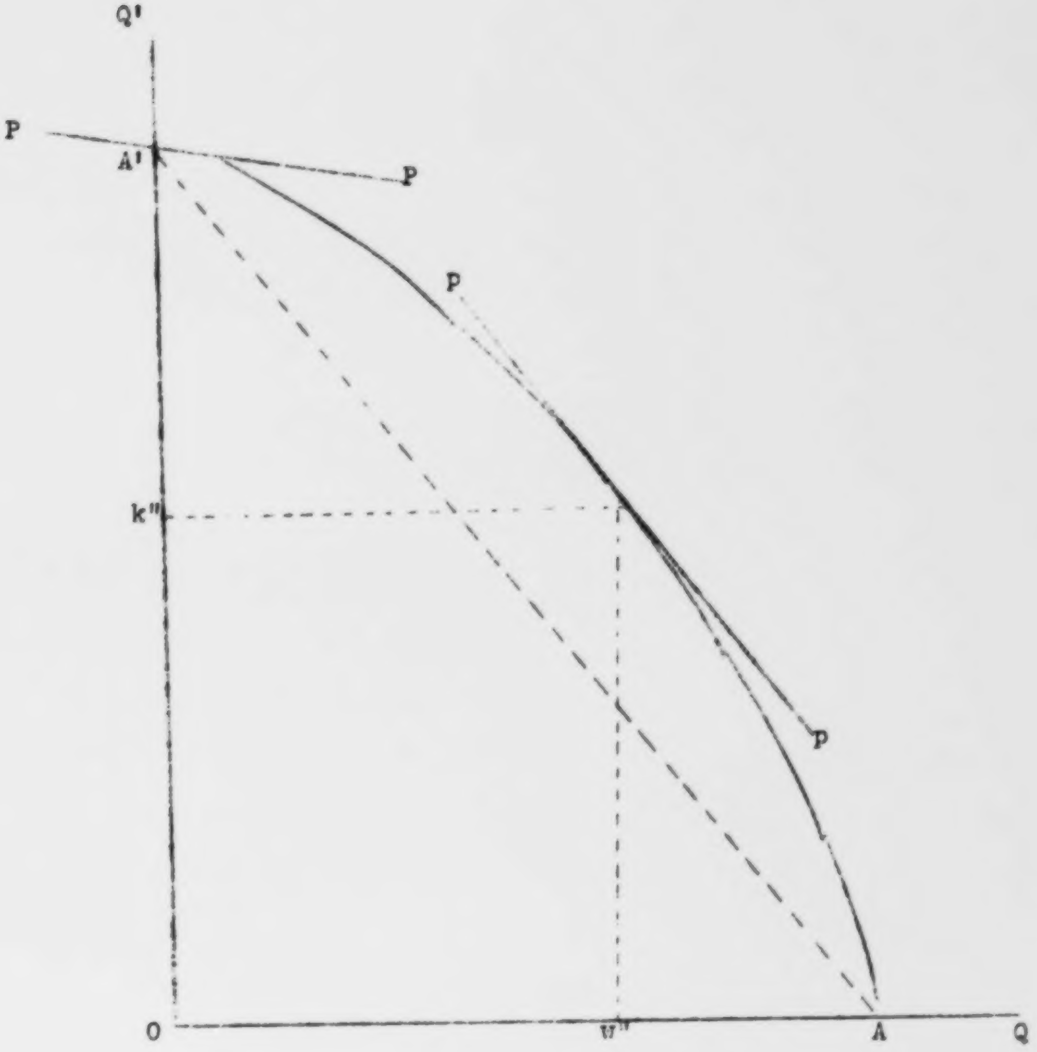
[22] Unless there is some "scale" effect upon output quality associated with movement along the scale lines of Figure 9, what is said here and in the next few pages does not apply to the pure output effect.

[23] One could imagine the vertical axis of Figure 9 as being a scale measuring the continuous deterioration of the output quality, while the abscissa, as before, measures the quantity of output that continues to be of the output quality existing before the initiation of air pollutant fumigations. However, given that quality differences are reflected only in the buyer utility a given output quantity can provide, a different demand function will be relevant for each point on the quality transformation function. Thus no unique price line can be defined and the conditions calling for convergence of the marginal rate of transformation and the price ratio could not be fulfilled--unless the impact of quality upon price could be normalized.

FIGURE 9

QUALITY TRANSFORMATION


Q'
P
A'
P
P
k"
P
O
U"
A
Q

fumigations just as readily have selected the input proportions along the scale line ON as along the scale line OM. The fact that he didn't implies that the quality of output obtained at A is superior to that obtained at A'. Thus, even though the advent of air pollutant fumigations may have caused the physical or quantity productivity of X_2 relative to X_1 to increase, the fact that X_2's unit contribution to receptor revenues continues to be less than X_1's weakens and diminishes the substitutability of X_2 for X_1. That is, quality considerations cause the substitutability of X_2 for X_1 to be less than would follow from quantity consideration alone. In other words, the desirability of the X_1 input bundle relative to the X_2 input bundle is greater than calculations of pollutant damage susceptibility based only upon changes in quantity productivity would have it appear. This implies that the receptor--if he knows what the air pollutant fumigations are doing to the quality of his output--is likely to employ some amount of X_1 less than w but greater than w', and some amount of X_2 greater than k but less than k'.

A situation where an increase in the production of one output results in a decrease in the production of another output--two different qualities of a commodity can, after all, be regarded as two different outputs--causes one to think immediately of a production possibility or transformation function. Transformation functions are always drawn on the assumption of equal total outlays for each and every point on the function. Suppose the rate at which Q is transformed into Q' as X_2 is substituted for X_1 is represented by the solid curve AA' in Figure 9. The dashed line AA', every point on which gives the total cost of any combination of Q and Q' in Figure 9, therefore represents the distance AA' along the isocost line ZZ in Figure 8. Similarly, the distance OA in Figure 9 corresponds to the distance w'w in Figure 8, and the distance OA' in Figure 9 corresponds to the distance kk' in Figure 8. The origin, O, of Figure 9 is thus located at the point w'k in Figure 8.

Since the transformation function given by the solid curve AA' in Figure 9 takes on the conventional shape, a decreasing marginal rate of transformation between Q and Q' is assumed.[24] That is, it is assumed that the rate of quality transformation of Q into Q' decreases as more and more X_2 is substituted for X_1. In other words, the more X_2 which has already been substituted for X_1, the less will be the increase in the proportion of the total output which will be of quality Q'. This is consistent with the principle of diminishing marginal productivity, for it implies that as the proportion of output of quality Q' increases, the (quality) marginal product of X_2, since more X_2 is now being used, must decrease. In the same sense, as the proportion of output of quality Q decreases, the (quality) marginal product of X_1, since less X_1 is now being used, must increase.

Given the assumptions of the preceding paragraphs and given the perfect quantity substitutability of X_2 for X_1, the receptor will be minimizing the impact of this less than perfect quality substitutability upon his net revenues when he minimizes its impact upon his gross revenues. Thus, according to well-known principles, this minimization will occur when the rate of deterioration in quality caused by the substitution of X_2 for X_1 is equal to the rate at which the market, as expressed in the market price ratio of the two different qualities, is willing to substitute Q' for Q. In Figure 9, the line PP represents an isorevenue function whose slope is simply the negative reciprocal of the ratio of the market price of Q' to the market price of Q. Since it is tangent to the quality transformation function at the point A', the damage function obtained by giving attention only to quantity productivity will not differ from that damage function obtained by giving attention to both quantity productivity and quality productivity. In this case, singular attention to quantity productivity alone or quality productivity alone will provide the same answers. However, if the isorevenue function is represented by pp, the receptor in order to maximize his net revenues will not substitute as much X_2 for X_1 as is implied by quantity productivity alone. In fact, given the quality transformation function, the less the unit price of Q' relative to the unit price of Q, the less the extent the receptor is likely to think it desirable to substitute X_2 for X_1 in spite of the ability of X_2 to maintain the receptor's quantity productivity at the same unit costs of production. Thus with the quality transformation function of Figure 9 and the isorevenue function, pp, of Figure 9, the receptor after the advent of pollutant fumigations will not use w' or X_1 and k of X_2, but will instead employ w" of X_1 and k" of X_2. Generally therefore, the greater the rate of output quality transformation as one input is substituted for another and/or the greater the price of one quality of an output relative to the price of another quality of that same output, the less likely is an attempt to be made to maintain quantity productivity.[25]

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[24] As the reader has no doubt noted, in contrast to the usual transformation function formulation the quantity of any one type of productive factor employed is not being held constant. But, since we are dealing only with the pure substitution effect, the quantity productivity of X_2 is always equal to the quantity productivity of X_1. That is, when viewed only in quantity terms the two inputs are perfect substitutes for each other. We are therefore justified in viewing them as only one input for purposes of constructing the quality transformation function.

Yet another problem remains with the usual formulation of the receptor damage function, though it seems to the writer that it is more a general problem of economics rather than a problem applicable only to the specification of receptor damage functions. To this point, the writer, in common with most economic analysts concerned with production functions and production relations, has assumed that the short-run properties of these relations can readily be carried over into the long-run. That is, that very assumption of the technological fixity of the durability of capital equipment which characterizes the short-run is carried over without modification when any generalization to the long-run is made.[26] In the air pollution context, a specification of a damage function which takes into account the aforementioned substitution and quality considerations may still when control measures are based on it lead to totally unexpected receptor and/or emitter responses if the assumption is made that pollution, however measured, will not affect the durability of highly immobile inputs. Although it certainly is true that "economic problems arise always and only in consequence of change"[27] and that "as long as things remain constant, there's no need to alter plans,"[28] this does not mean it is correct to assume that the only alterations or adjustments which can ever be made are solely in terms of the rate of use of an input or inputs. To assume such is to neglect at least one-half of the possible modes of adjustment and alteration. The other half of these modes will be included only when explicit consideration is given to the time interval over which the damage function in question will continue to be operative and therefore relevant.

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[25] It is of course the case that pollutant fumigations can affect the quality as well as the quantity derived from the input, X_1, most susceptible to pollution damages. This, however, in no way affects the above conclusion, for that conclusion is stated in relative terms.

[26] This carrying over is now beginning to receive a good deal of intensive scrutiny and extensive criticism in the literature. Cf. Erik G. Furubotn, "Investment Alternatives and the Supply Schedule of the Firm," Southern Economic Journal, 30 (July, 1964), pp. 21-37; Erik G. Furubotn, "The Adaptability of Fixed Productive Services in the Short Run," Southern Economic Journal, 28 (April, 1962), pp. 329-339; and Nicholas Georgescu-Roegen, "Chamberlain's New Economics and the Cost of Production," in Robert E. Kuenne (ed.), Monopolistic Competition Theory: Studies in Impact, (New York: John Wiley & Sons, Inc., 1967), pp. 31-62.

Consider the decision variables in which a firm, whether it be an emitter or receptor, is interested when it must select from among several possible production strategies. As is generally recognized, the firm, given the expected conditions of demand for its outputs and its potential inputs, decides to produce that quantity of output per unit time which will maximize the present value of the flow of some numeraire: net revenues, managerial security, the firm's competitive position, some set of interactions of these terms, or have what you will. However, this typical formulation nearly always neglects an important consideration: the interval of time over which the output and its associated input mix are expected to be optimal. Yet, clearly, the input mix the firm selects will vary with the time interval over which the conditions necessitating this optimal input mix are expected to continue. In general, the longer the interval, the greater the extent to which the firm can afford to invest in durable equipment; and the shorter the interval, the less the extent to which the firm is able and willing to make such investments. If and only if the time interval the firm considers relevant for its planning decisions is the same regardless of supply and demand conditions can one be sure that concentration upon rates of output alone will lead to the same answers as will devoting dual attention to rates and to volumes. Only where the time intervals being considered are the same will the two notions of rate and volume separately conceived be equivalent and lead to the same results. In order to move from the quasi-abstract, consider the following example which serves fairly well to show the rather ridiculous results to which sole attention to rates can lead.[29]

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[27] F. A. Hayak, "The Use of Knowledge in Society," The American Economic Review, 35 (Sept. 1945), p. 523.

[28] Ibid.

Suppose we are interested in determining the damage function which relates fluoride ingestion to the slaughter weight and grade of beef cattle. Now assume that after a search of the literature, we find two sources which appear to contain the information we desire.

The findings set forth in one source indicate that a beef steer can ingest a very high volume of fluorides over a short time interval and not be adversely affected--say one thousand units over ten hours. The findings in the second source indicate that a beef steer allowed to ingest relatively small quantities of fluoride over a long time interval will be seriously affected--say ten units over one thousand hours. In accordance with our usual practice, we make the two disparate time intervals commensurate by the simple expedient of dividing the accumulated volume of fluoride ingested by the number of hours over which the ingestion took place. We therefore end up with a factor stated in terms of fluoride ingested per hour, i.e., the rate of fluoride ingestion. And, assuming the money value of each additional pound of beef of a given grade to be a constant, our "analysis" shows that cattle which ingest fluorides at high rates suffer little damage, while those which ingest fluorides at low rates suffer substantial damage. We would therefore recommend to the receptor who wishes to minimize damage costs to his beef cattle that if they must ingest fluorides at all they be made to ingest them at very high rates--something on the order of one hundred units per hour. The higher the rate, the less the money value of damages; and the less the rate, the greater the money value of damages. Of course, when faced with this bit of foolishness we would realize that something is being left out. That something is, of course, cumulative volume: a variable that cannot be taken into account unless explicit attention is given to the time interval over which a given rate is expected to be applicable.

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[29] It may in fact seem rather ridiculous to even bother with these points since they are, after all, rather apparent. But apparent or not, they have received little attention. The reader will recognize this if he takes the trouble to write or draw a simply supply and demand function and then gives some thought to the manner in which the time dimension generally enters this function.

This concentration upon rates without specification of the time interval over which a given rate is expected to hold can lead to very serious biases in pollution damage estimates and pollution cost-savings estimates. These biases are mainly reflected in a failure to recognize that pollution has an effect in addition to causing shifts in the value productivity functions (stated in terms of rates) of inputs and substitutions(again stated in terms of rates) as between and among inputs. In the case of an increase in the level, however defined, of air pollution fumigations, this other effect is an erosion or contraction of the time interval over which the present site use with its associated input mix will be economically viable and an expansion of the time interval over which the present emitter site use with its associated input mix will be economically viable. In short, the input mix which a receptor or emitter employs is not independent of the level of pollutant fumigations and/or emission, and this input mix is not independent of the time interval over which it is expected that a given volume and value of output can be maintained.

A change in the time interval over which a given input mix in an air pollution problem is expected to be economically viable can be brought about by a change in any one of four different variables: (1) the total expected volume of air pollutant fumigations or emissions: (2) the length of the time interval over which fumigations or emissions are expected to occur; (3) the expected rate of pollutant fumigations or emissions; and (4) the point in time at which the first pollutant fumigation or emission associated with any one production program of emitters is expected to occur.[30] That is to say, everything else being equal, the time interval over which a given input mix is expected to be economically viable is a direct function of the level of air pollution damage costs. These damage costs are a direct function of the volume of pollutant fumigations. That is $C_d = f(V)$, where C is damage cost and V is the volume, in whatever units it is measured, of pollutant fumigations. In turn, V is given by the following expression:

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[30] A change in the time interval over which a given input mix is expected to be economically viable can also be brought about by holding the four temporal variables for emissions constant and varying the land space devoted to any one emitter and/or receptor input mix. However, at least for receptors, the effect of such a measure would still be to cause one or more of the four temporal variables to change.

$$V = \int_{t_0 + H}^{H+u} a \, dt$$

where u is the length of the time interval over which pollutant fumigations are expected to occur, H is the point in time at which the initial pollutant fumigation is expect to occur, a is the expected rate of pollutant fumigations, and t is time. It is therefore obvious that:

$$C_d = \int_{t_0 + H}^{H+u} a \, dt$$

Thus, everything else being equal, receptor damage costs will become greater as a increases and as H moves closer to the present. That is,

$$\frac{\partial C_d}{\partial a} > 0; \quad \text{and} \quad \frac{\partial C_d}{\partial H} < 0.$$

As for the receptor u, it is difficult if not impossible to generalize about it. Given a specific volume of pollutant fumigations, it is not impossible to find cases where less damage is done to the property of receptors if the time interval over which pollutant fumigations take place is shortened. For example, experiments provide some evidence that cattle, because of their partial ability to rid themselves of fluorides through their gastro-intestinal tracts, are less affected by relatively large quantities of fluoride over shorter periods of time than by relatively small quantities of fluoride over somewhat longer periods of time.[31] On the other hand, studies with alfalfa indicate that the plant will experience greater damage if exposed to relatively large quantities of sulfur dioxide over relatively short periods of time.[32] Thus, since the sign assumed by the change in damage costs as the receptor u varies differs according to the type of receptor and possibly with the type of pollutant, its determination is likely to be the most difficult measurement problem faced by the investigator--particularly in a situation where there are several types of pollutants and/or several types of receptors.

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[31] P.H. Phillips, "The Effects of Air Pollutants on Farm Animals," in Paul L. Magill, et. al. (eds.), Air Pollution Handbook, (New York: McGraw-Hill Book Company, Inc., 1956), p. 7.

In any case, it is apparent $\partial C_d/\partial a$ and $\partial C_d/\partial H$ do not have the same sign. Similarly, there is no reason always to suppose $\partial C_d/\partial a$ and $\partial C_d/\partial u$ are equal or even have the same sign, just as there is no reason to assume that $\partial C_d/\partial H$ and $\partial C_d/\partial u$ always are equal or have the same sign. Therefore, for example, if the receptor expects the rate of pollutant fumigations to increase, he might find it advisable to increase the interval of time over which he employs a given input mix and/or to initiate his use of a given input mix as a point in time farther into the future. Or it might be best (economic) for him to do just the opposite. The essential point is that for this receptor these time dimensions constitute a set of substitution possibilities in addition to those physical substitution possibilities which were earlier made note of. Any properly and reasonably fully specified damage function must take them into account.

To make the above point clear, the reader need only consider the previously mentioned example in which cattle are detrimentally affected by low rates of fluoride ingestion occurring over a relatively long interval of time. The owner can thus ameliorate the fluoride's detrimental effects by shortening the time interval over which any one animal is allowed to graze on pasture grasses containing fluorides. If the pasture's owner wishes to maintain the beef yield he obtains from the pasture at something approximating its level before the advent of pollutant fumigations, he will have to allow more animals to graze on the pasture. Though this amounts to increasing the rate at which the animals are allowed to feed on the pasture, it also means that the time interval over which any given rate is applicable is shortened. The greater rate of feeding upon the pasture means that the rate at which the pasture deteriorates is increased, i.e., the economic life of the pasture is contracted. As is well-known, outputs earlier in the future are less heavily discounted. The same is of course true for the cost of the input fed to the animals. Nevertheless, grazing the pasture at greater intensity, i.e., over any given interval of time putting more animals per square foot upon it than previously, might be more profitable than grazing it at lesser intensity. It would in fact be more profitable even if the pasture deteriorates at a more rapid rate as long as the extra deterioration of the pasture is not so much higher when it is intensively grazed as to negate the gain in interest which would accrue to the pasture owner. The returns which formerly would have accrued only in the latter years of the pasture's economic life have now at least partially been brought closer to the present and are therefore less heavily discounted. As long as the present value of this gain outweighs the present value of the increased wear and tear on the pasture, the receptor will minimize his losses from pollutant fumigations by grazing the pasture more intensively. Thus when trying to specify damage functions or when trying to establish criteria for the specification of damage functions, explicit and very careful consideration must be given to the interval of time to which attention is to be devoted.

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[32] P. J. O'Gara, "Abstract of Paper, Sulfur Dioxide and Fume Problems and Their Solutions," *Industrial and Engineering Chemistry*, 14 (June, 1922), p. 744.

II. THE MEANS OF MEASUREMENT

The obvious implication of the preceding section is that any air pollution damage measurement technique which fails to take into account the temporal and physical substitution possibilities open to receptors must err seriously. Since the whole purpose of damage measurements is to ascertain at least one of the two sides of the terms of exchange between receptors and emitters, the manner in which damages are measured can have profound effects upon the exchange terms and therefore upon the exchange system or control system which is established. If the means of measurement employed fail to take into account some of the individual receptor adjustments and interactions to variations in expected pollutant fumigations, then the damage estimates which are obtained must be biased. Any control system which is founded upon these biased estimates must therefore itself be biased in that it will place too little or too much weight upon the provision of an additional unit, however measured, of the air's waste disposal dimension or the air's life and property supporting dimension.

The means available for measurement of air pollution damages are essentially two--the sample survey approach and the land value approach. The former or the sample survey approach employs data from the natural and physical sciences dealing with the relations between pollutant fumigations and a damage indicator, as well as survey material dealing with the individual adjustments over time of receptors to variations in pollutant fumigations. This sample survey approach thus requires intimate knowledge of all the relevant receptor technical coefficients of production, in addition to knowledge of each receptor's utility function. For each receptor in the sample, every logically possible and mutually exclusive set of adjustments the receptor could make to minimize the effects of the pollutant fumigations must be accounted for. After having identified these adjustment possibilities, the investigator must discern which adjustment or set of adjustments was selected by each receptor. He must then explain why each receptor chose one set of adjustments rather than another set. Finally, after having found some means of making individual receptor adjustments commensurate, he must aggregate--only rarely will this aggregation process involve a straightforward arithmetic summation--over all individual receptors so as to obtain a receptor damage function. All this requires the investigator to consider carefully such matters as between and among individual receptors as differences in managerial efficiency, differences in the qualities of specialized factors of production, differences in the ages and types of those specialized factors of production which have not been fully depreciated, differences in the factor proportions and scales which have been, are, and are expected to be optimal over varying intervals of time, and, finally, the possible interactions of these differences. Some investigators might enjoy attempting the sample survey approach just because of its sheer difficulty;[33] however, an easier approach--the land value approach--is available which enables one to avoid most of the aforementioned difficulties of the sample survey approach.

The basis of the value of any location in space, i.e., any land site, is the stream of net returns expected to be forthcoming from that facility. If a site is being used for a particular purpose and will continue to be used for that same purpose, its present market value is the discounted market value of the expected future net returns to the site when used for that purpose. That is, its discounted market value and therefore its present market value is:

$$P = \sum_{t=1}^{n} \frac{S_t}{(1+r)^t}$$

where S is the net returns to the site if it remains in its present use, n is the last year the market would have the site kept in this use, and r is the market discount rate. S takes account of changes in the intensity of any one use since it represents expected net returns in any one year or period t.

If a change in receptor damage costs from pollutant fumigations causes another site use or mix of uses to be expected to earn greater net returns ultimately than that use or mix which formerly was expected to earn the greatest net returns, then the present market value of the site will be:

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[33] From the purely practical point of view, the data problem alone makes the sample survey approach of questionable feasibility. It is difficult to conceive of an adequately large sample of individual receptors being willing to supply the information necessary for the use of this approach. Furthermore, in most air pollution situations, much such information won't even exist, for the required burden of record-keeping would be extremely great.

$$P_c = \left(\sum_{t=1}^{n} \frac{S_t}{(1+r)^t} \right) + \left(\sum_{T=n+1}^{m} \frac{S^*_T}{(1+r)^T} \right)$$

where P_c is the present "conversion" value, S^* is the expected net return to the site in year T, and m is the last year the site will be kept in the new use. P_c must necessarily lie somewhere between the present market value of that use which is first in time and that use which is or will be last in time. In general, the smaller and the less immediate the impact of the change in receptor damage costs, the more nearly equal will the present conversion value be to the present value of that use which is first in time. However, as t approaches T, the effect upon value of that use which is first in time will be minimal. In any case, the present value of that use which is last in time will be greater at some point in time than the present value of that use which is first in time, for a site would not have another use if the earlier use continued to be a higher order.

The concepts briefly outlined in the preceding paragraph apply to situations where changes in intensity of use and conversions in the uses of receptor sites are brought about by general market forces as well as by changes in receptor damage costs. But, assuming that the general market forces which may differentially affect individual receptors can be specified, these concepts do provide a basis for determining the differential impact of changes in the temporal and/or spatial distribution of pollutant fumigations which affect receptor damage costs. Furthermore, they provide a basis for comparing changes in intensity and conversions in the uses of receptor sites in an area where there are differences as between and among locations with respect to the extent of pollutant fumigations.

When the rate, volume, time interval, or starting point of pollutant fumigations changes in a manner which causes the intensity of any one receptor site use to change, the receptor damage costs are the present value of the expected foregone net returns in n-n', where n' is the last year the site use will be allowed to continue with the change in use intensity, plus the expected reduction, if any, in the present values of S_t taking place over the new economic life of the site use. Similarly, when a change in the rate, volume, time interval, or starting point of pollutant fumigations changes in a manner which brings about an expectation of a conversion of receptor site use, the receptor damage costs are not simply the reductions in the present values of S_t over the old economic life of the site use, but these reductions plus the present value of the differences between S_t and S_T^* in n-n' plus the present value of any changes in S_T^* after n. In any case, receptor damage costs are equal to the present values of the expected net returns foregone over both the old and the new economic lives of receptor site uses. To the extent that the number of receptor sites traded over any one interval of time is substantial, that the sites are in fact perfectly price inelastic with respect to supply while all other factors of production used in conjunction with the sites are instantaneously mobile, that all other influences which can differentially affect land values can be shaken out, and that there is a moderate degree of conformity in the expectations of buyers and sellers with respect to future events and their effects upon the sites, differential site values as reflected in differential site sale prices will closely approximate the differences in receptor air pollution damage costs.

Certainly, the above conditions will rarely if ever be completely fulfilled. Many forms of real capital are at least partially immobile and, to the extent they are immobile, their capitalized values will also reflect the differential air pollution damages associated with various locations. Since many of the participants in land value transactions are active in the land market very rarely, there is less likely to be substantial convergence of expectations about future events than would be the case where the individual's market activities take place with relatively great frequency.[34] Furthermore, even if all the above conditions are fulfilled, there still remains a rather heated discussion among economists as to whether or not that market discount rate employed in the determination of land values is greater than the socially optimal rate of discount.[35] To the extent that the market rate is greater than the optimal rate, those portions of differential land values attributable to damages from air pollutant fumigations understate the social costs of air pollution. Finally, the use of land values to determine differential air pollution damages does not yield information directly relevant to the design of air pollution control systems and measures.[36] That is, in the process and as a by-product of calculating air pollution damages, one does not need to determine the values assumed by many parameters which might prove to be relevant to the design of an air pollution control system. Instead, one must infer what might have caused these land value differentials from their spatial and their temporal distributions, as well as from a knowledge of the non-air pollution factors which might have brought about these differentials. However, it is difficult to see why it makes much difference whether or not one works back to the supposed causes or whether he works from the supposed causes. In either case, if both approaches are properly used in the sense of internal consistency and if their assumptions are fulfilled, the results are the same.

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[34] This convergence is far more likely to occur when the sites are devoted to similar production-oriented uses rather than to diverse consumption-oriented uses. The Polk County land value data to be presented in Chapter V is very heavily weighted with similar (citrus and cattle) production-oriented uses. If the writer may be allowed to digress a bit, the bringing about of a convergence of expectations can be argued to be the major contribution of the intellectually much despised and often criticized "jawbone" technique of persuading the parties concerned to adopt new courses of action in situations where the present course is thought to be unsatisfactory because of negative interpersonal effects. Rarely, if ever, is it recognized that these techniques to the extent to which they are workable do serve as an alternative to the imposition of non-voluntary economic and/or legal controls. The jawbone technique can serve to modify ends without changing the mix of means by which these ends can be attained and without destroying the setting in which these ends are to be embedded.

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[35] This discussion has two facets: (1) that the market for money capital is an imperfect market; and (2) that mainly due to external effects the social rate of time preference is less than the aggregate of individuals' rate of time preference. A discussion of the first facet is available in A. G. Hart, Money, Debt, and Economic Activity (New York: Prentice-Hall, Inc., 1948) pp. 202-203. The major statements of the second facet are to be found in S. Marglin, "The Social Rate of Discount and the Optimal Rate of Investment," The Quarterly Journal of Economics, 77 (Feb. 1963), pp. 95-111; and in R. C. Lind, "The Social Rate of Discount and the Optimal Rate of Investment: Further Comment," The Quarterly Journal of Economics, 78 (May, 1964), pp. 336-345.

[36] Allen V. Kneese, Water Pollution: Economic Aspects and Research Needs, (Wash., D.C.: Resources for the Future, Inc., 1962) pp. 44-45.

In spite of the slight probability of ever fulfilling all the conditions necessary for the perfect operation of the land value approach to the determination of air pollution damages, the approach still possesses in most situations what are likely to be substantial initial advantages over the sample survey approach, including in the latter the various forms of systems analysis. Generally, this is simply because the number of parameters which must initially be estimated in the land value approach is a good deal smaller than with the sample survey approach. Since the number of parameters to be estimated is smaller in the land value approach, this latter approach necessitates fewer assumptions and involves less required information about receptor technical coefficients of production, managerial efficiencies, ages, types, and qualities of specialized factors of production, expected output prices and input costs, receptor responses, etc., etc., ..., *ad infinitum*. Furthermore, in the sample survey approach, the accuracy or precision of many estimates is directly dependent upon the accuracy or precision with which estimates of other parameters have been made. The greater the number of parameters which must be estimated and the greater the number of these parameters whose estimates are dependent upon each other, the greater is the risk of erring badly in the final determination of the damage function. The accuracy with which a parameter is estimated that is a function of another already estimated parameter cannot in fact be any greater than the accuracy of the estimate for the already estimated parameter. Thus, for example, if the effect of a freeze upon the yield of a citrus tree can be estimated with a confidence interval of only plus or minus ten per cent, one cannot hope under any circumstances to estimate the effect of airborne fluorides upon that tree's yield with a confidence interval any greater than plus or minus ten per cent. In the land value approach, the estimates of many of these dependent or simultaneous relations are made by and in the land market inself. In short, using econometric terminology rather loosely, the land market rather than the investigator derives the reduced form equations for the estimation of air pollution damages from the basic structural equations.

Since the resources available to the writer for the investigation of air pollution damages to citrus and cattle in Polk County were scarce, it was felt that some attention should be given to an economy of research effort. Taking note of the lack of knowledge about the effects of airborne fluorides upon the technical coefficients of production for citrus and beef cattle that was pointed out in Chapter III, it seemed apparent and entirely within the realm of scientific possibility that any efforts by the writer directly to further this knowledge could yield only extremely low relative economic returns. That is, it was felt that the "scientific objectivity" implicit in the direct estimation of all the relevant basic structural relations could only be synonymous with an utter lack of economic objectivity. Therefore, the air pollution damages to the Polk County citrus and beef cattle industries have been estimated by means of land values rather than by estimating all the basic structural relations.

The results of the land value approach as applied to Polk County are reported in Chapter V.

III. THE USE OF MARKET PRICES IN THE DETERMINATION OF AIR POLLUTION DAMAGES: A DIGRESSION

Earlier in this chapter, allusion was made to the fact that for many people the buying and selling of land is a once-in-a-lifetime matter. For this reason it was asserted that particularly where the use of land is primarily consumption rather than production-oriented, there is likely to be a substantial divergence of expectations among individual users of the land as to the effect of future events upon the land's value. To the extent this divergence of expectations exists, sites having similar physical attributes will sell for widely varying prices. If the frequency of sales is fairly great and if a representative sampling of sales can be obtained, there should nonetheless tend to be a grouping of the sale prices of sites having similar attributes around some sort of average or mean--not necessarily arithmetic--sale price. The dispersion of sale prices around this mean can readily be described by common statistical measures. However, even when the difficulty of divergent expectations is substantially overcome, another and somewhat similar problem remains.

Basing calculations of damages caused by any given level of pollutant fumigations for any one set of receptor sites upon the sale prices of another set of seemingly comparable receptor sites assumes that the schedule of marginal reservation prices for the former group of receptors is the same as the schedule of marginal reservation prices of that group of receptors who actually sold their sites. An air pollution damage function calculated or derived from changes in land values for those receptor sites which have been placed upon the market means that those receptors who place the lowest marginal valuation upon reducing the frequency and/or the concentration of pollutant fumigations (those whose marginal damages are lowest) are to be allowed to determine the relative harshness of controls to be imposed upon emitters. One would instead suppose that it is those who place the highest marginal valuation upon cutting back the severity of pollutant fumigations who would be consulted in determination of the relative harshness of emitter controls, since in a perfectly competitive market which maximizes the air resource's rent it would be those having the highest valuations who would be the market participants and would thus determine the relative harshness of emitter controls. However, the use of the market prices of receptor sites--or, for that matter, any market price--as indicators of air pollution damages enables those having the lowest marginal valuations of cleaner air to determine the extent to which cleaner air is found to be worthwhile. Though it be true that "economic analysis facilitates judgments among alternatives by reducing all to a common measure,"[37] and though "the economist's measure, exchange value, serves as a means of communication and reconciliation,"[38] there is at least one group whose alternatives are not being fully considered by the common measure and whose needs are not necessarily being completely reconciled: the nonparticipant in the market.

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[37] Mason Gaffney, "Applying Economic Controls," Bulletin of the Atomic Scientists, 21 (June 1965), p. 20.

[38] Ibid.

In the usual adage, if the individual does not like what the market is offering, he need not participate. But the use of market-determined values as the only indicator or measure of air pollution damages to the nonparticipating receptor forces that individual to accept the market's valuation regardless of his views about what the market is offering. Since the economist's conceptual framework assumes that both buyer and seller have free choice as to whether or not they will enter the market, the use of market values to determine the damages imposed upon those who have not yet chosen to enter the market seems more than a little inconsistent. The option of the receptor who does not yet choose to enter the market is being removed from him. In its place is being substituted the market's view as to the value of the nonparticipating receptor's inputs and/or outputs: the market's supply price is being substituted for the nonparticipant's supply price. The market therefore takes air pollution damages into account only insofar as these damages are reflected in actual sales. To assert that the allocation of the air resource resulting from the use of these market evaluations is exactly the same as that which would occur in a perfect market in rights to the use of the air resource is to have a quite imperfect understanding of the welfare implications of the market. And to cloak this imperfect understanding in talk about the inability of the "average" person to understand sophisticated analytical techniques confuses nobody. The widow, though compensated at existing market prices, who is losing her lifelong home to the expressway engineer experiences no real difficulty in perceiving and understanding her losses.

Consider the following figure, Figure 10. R_1 and R_2 show the marginal reservation prices for two groups of receptors owning sites with highly similar physical and locational attributes as a function of the absolute level, however measured, of pollutant fumigations. The negative slopes of R_1 and R_2 show that the level of pollutant fumigations and receptor marginal reservation prices for their sites are assumed to be inversely related. Now suppose that S is the marginal offer function of those who would purchase the receptor sites. This offer function is assumed to be invariant with respect to the level of pollutant fumigations. The potential buyer might, for example, be a mining company to whom the sites' surface attributes have no interest. R_1 and R_2 do not come below S, because if they were to do so it would mean that the receptors would be willing to pay somebody to take the sites off their hands. The reservation prices of the R_2 group's members and the offer function of the potential buyer are assumed to be independent of the number of sites placed on the market by the R_1 group.

The marginal reservation price function of the R_2 group of receptors is presumed to lie above that of the R_1 receptor group because the members of the latter are strictly production-oriented--they think only in pecuniary terms--while the former or R_2 receptor group's members obtain consumption as well as production benefits from their ownership. Members of the R_1 receptor group might, for example, be interested only in the production of citrus fruit, while the R_2 group's members, while they too are interested in producing citrus fruit, also

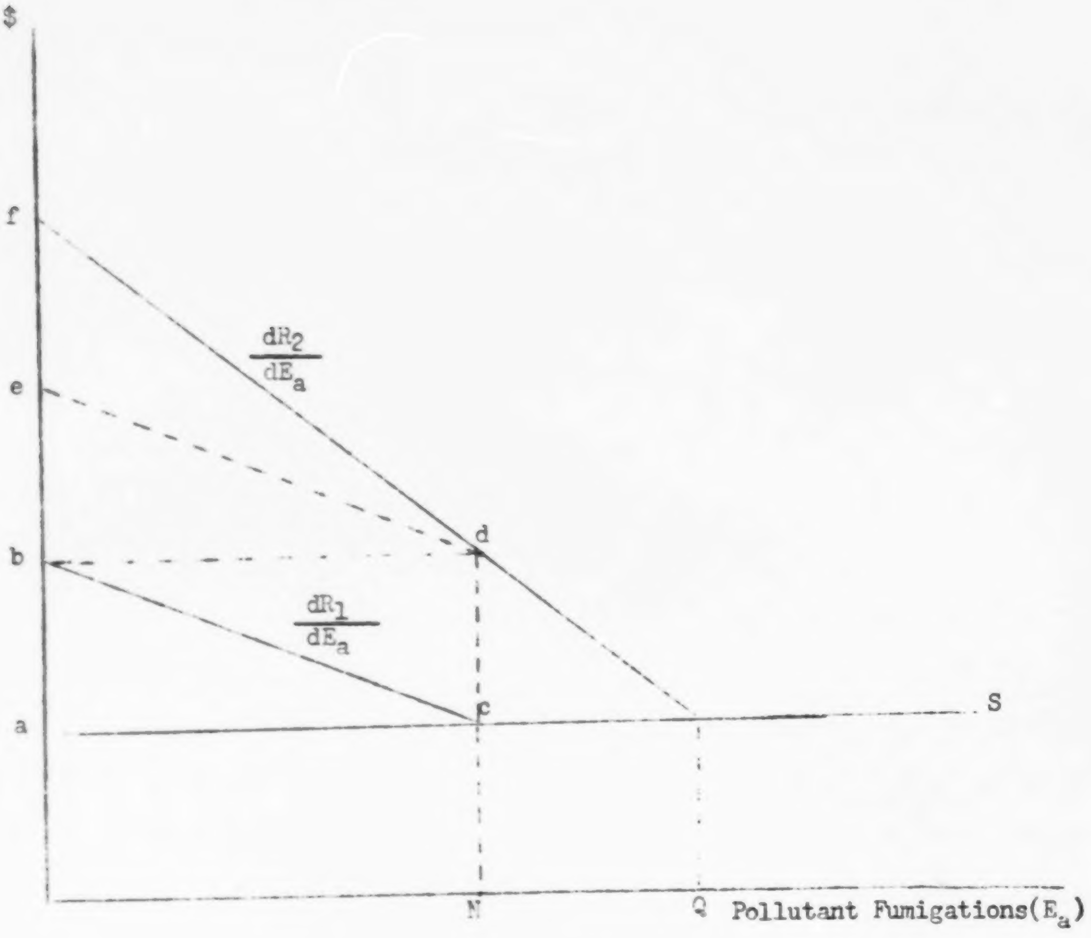

FIGURE 10
RECEPTOR RESERVATION PRICES
AND
MARKET EVALUATIONS OF RECEPTOR DAMAGES

obtain nonpecuniary psychic benefits from their ownerships. These psychic benefits might consist of the enjoyment derived from seeing long, undulating rows or citrus trees, whether healthy or unhealthy, the rather pleasing coolness in a hot and sweltering climate to be found in the trees' shade, or even the status derived from being a citrus grove owner. The R_2 group of receptors attach a value to these psychic benefits and they would count their loss as a foregone return, even though they might not be able to afford to pay cash for the value they place upon these nonpecuniary benefits. For the R_2 group of receptors these psychic benefits the citrus grove is capable of providing are, we will assume, strictly complementary, i.e., they are joint products with the production of citrus fruit.[39]

For each and every point on the pollutant fumigations axis, $2R_1$ is drawn equal to R_2. When the level of pollutant fumigations reaches N, all the R_1 receptors will sell their sites because further increases in pollutant fumigations would reduce the capitalized value to them of their sites below the value they place upon the dollars they can receive by selling. However, the R_2 group of receptors would continue to hold on to their sites until the level of pollutant fumigations given by Q is reached because their marginal reservation prices are still higher than the price at which they are able to sell their sites.

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[39] For more on points similar to those made in this paragraph, see William E. Martin and Gene L. Jefferies, "Relating Ranch Prices and Grazing Permit Values to Ranch Productivity," Journal of Farm Economics, 48 (May, 1966), pp. 233-242.

With the level of pollutant fumigations given by N, the total damages from pollutant fumigations to each individual in the R_1 receptor group are equal to the dollar equivalent of the area abc. This area, abc, when doubled, or when the area bde is added to it (abc = bdc = bde), and when multiplied by the number of all receptors, whether in the R_1 or R_2 group, will provide an accurate estimate of the reduction in the capitalized values of all receptor sites--given the assumption that all receptors march only to the drum of production. However, as already noted, not all receptors are in the R_1 group. The assumption that all receptors are in the R_1 group will lead to an underestimation of total receptor damages equal to the dollar equivalent of the area bdf multiplied by the number of receptors in the R_2 group. In short, the fulfillment of the assumption that all receptor sites have homogeneous physical and locational attributes does not justify the extension of this assumption to the point where the site owners themselves are considered to be homogeneous.

The above result is dependent upon the R_1 and R_2 marginal reservation price schedules having different slopes. That is, the result is dependent upon $\frac{d^2R_1}{dE_a^2} \neq \frac{d^2R_2}{dE_a^2}$, where E_a is pollutant fumigations. If $\frac{d^2R_1}{dE_a^2} < \frac{d^2R_2}{dE_a^2}$, then the total and marginal receptor damages that are obtained will be less than actual receptor damages, while if $\frac{d^2R_1}{dE_a^2} > \frac{d^2R_2}{dE_a^2}$, the use of market prices will overestimate actual total and marginal receptor damages. But when $\frac{d^2R_1}{dE_a^2} = \frac{d^2R_2}{dE_a^2}$, actual and estimated total and marginal receptor damages will coincide. This is easily seen from Figure 10, for when the slopes of the two reservation price schedules are the same, the area abc will be equal to the area bdf: R_1 and R_2 total and marginal receptor damages are equal. Similarly, if abc is greater than bdf, actual damages will be exaggerated; and if abc is less than bdf, as is the case in Figure 10, underestimation of actual damages will take place. In short, all that need occur to introduce a bias into damage estimates is for the proportionate contribution of nonpecuniary relative to pecuniary considerations to the receptor's marginal reservation price schedule to vary from one level of pollutant fumigations to another.

In and of itself, the extension of the homogeneity assumption or the shaking out of all dissimilar physical and locational, i.e., fairly readily quantifiable, site attributes to or from the site owners cannot be considered a matter of serious import so long as each owner of a receptor site makes his production, consumption, and sales decisions independently of every other owner. However, if the estimated reductions in land values are to be used for determination by some properly constituted authority of the allowable level of emissions or pollutant fumigations over some given interval of time, then the matter does take on serious proportions. If only the private market in land or in readily quantifiable physical and locational site attributes is to be considered in the determination of receptor damages, then those receptors in the R_2 grouping will have no way to make known the damages they have suffered.[40] According to received doctrine, if the individual disapproves of what the market is offering, he need not participate. But the use of market-determined land values as the only indicator or measure of air pollution damages to the R_2 receptor forces that individual to participate in the market regardless of what he thinks about what the market is offering.

The above phenomenon is simply another instance of externalities--a failure of individual nonparticipation parties' values to enter into the calculations of the transacting parties, even though the transacting parties decisions enter into the calculations of the nontransacting parties. As a result, any public authority which bases its allocation decisions on the relative values of only the contracting parties may cause the total effect of the allocation decision to fall short of a collective optimum. Though the problem is an externality problem, the failure implicit in it is not due to the market itself but rather to the lack of inclusiveness flowing from the use of market valuations by air pollution control authorities. In other words, the use of market valuations alone causes the allocative decisions by the air pollution control authorities based on these market valuations to have external, unconsidered effects. The process of calculation itself--solely because of its lack of inclusiveness for the use to which it is to be put and not because of any necessary inherent fault in the market--generates externalities.

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[40] They can of course resort to political measures. However, the damages implied by the response to any political measure are obviously unlikely to conform to that amount of money which would cause the R_2 type receptor to be indifferent between keeping his site and selling it. Another alternative which might be employed is the courts, but generally the only damages the courts will consider are those which are quantifiable in the simplest possible sense, e.g., the reduction in this crop year's yield times the crop's unit price.

In summary, then, any calculation procedure employing only market values, i.e., the values of those who for one reason or another participate in the market, can bias any estimate of total and marginal air pollution damages. Furthermore, it is not unreasonable to presume that the level of pollutant emissions an air pollution control authority will allow over any one interval of time will vary inversely with what is thought to be the level of receptor damages caused by pollutant fumigations. If one group of receptors does not participate in the market because it holds higher reservation prices than the market participants and if the former's marginal reservation prices with respect to varying levels of pollutant fumigations are not some fixed multiple of the latter's marginal reservation prices, any procedure which estimates air pollution damages by summing over equally weighted individual receptors must provide inaccurate results. If damages are underestimated, then greater than optimal levels of pollutant emissions, fumigations, and receptor damages must ultimately occur; if overestimated, then suboptimal levels of emissions, fumigations, and receptor damages will sooner or later take place. That is, emissions will not occur from which emitters would receive greater benefits than would receptors with the nonoccurrence. Any reasonable scheme for air pollution control must therefore provide those receptors who don't participate in the market with an opportunity to express their value orderings and to have these preferences reflected in the allocation decisions made about the air's two value dimensions. This opportunity might necessitate some direct and after the fact adjustment by the control authority in market values it employs in its calculations, or it might involve some scheme which would cause the valuations of non-participating receptors to be reflected in the transactions which take place between participating receptors and the buyers of their sites. In any case, any measurement approach must err which focuses solely on visible quantities and values to the exclusion of other types of values that would be visible only in a market in which participation is strictly voluntary. In many instances, this latter type of value may be much more significant.

CHAPTER V

DESCRIPTION AND ANALYSIS OF SAMPLE DATA ON LAND VALUES

The data for the Polk County land value study were largely secured in the summer of 1964 from the local offices of various Polk County public agencies. The approach was to obtain information about actual open-market sales of land in agricultural uses at the time of sale, and to analyze by single equation, cross-sectional multiple regression techniques the influence of citrus grove age, acreages of various types of pasture, assessed values of improvements, and other factors on the selling prices of these agricultural sites. Separate analyses of the cattle and citrus industries have been made.

1. SOURCES OF DATA

Information about bona fide sales of Polk County agricultural lands fulfilling certain later to be specified requirements and occuring between September 1, 1947 and July 31, 1964, was obtained from a random sample of county deed books, real property tax assessment records, and the files of various private real estate agencies.

For each usable transfer of agricultural property the following information was obtained from county deed books: names and places of residence of buyers and sellers; day, month and year of sale; total selling price or amount of State of Florida and/or Federal revenue stamps required for the deed's registration; total number of acres transferred; and the location of the transferred site.[1] The assessed

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[1] Federal taxes are collected on all deeds at the time of recording with the payment of these taxes being certified by affixing stamps to the deed. In addition, Florida collects a tax at the time of sale for each registered deed and acknowledges the tax's payment by

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value of improvements and all other site attributes was obtained from Polk County real property tax assessment records, local offices of the Florida State Board of Health and the Polk-Hillsborough Air Pollution Control District, files of local real estate agencies, county highway maps, and United States Geological Survey topographic and isopach maps.

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also attaching stamps to the deed. The Federal tax is 55¢ per $500 or fraction thereof of the cash or cash equivalent transferred from the buyer to the seller at the time of sale. The state tax is 20¢ per $100 or fraction thereof (10¢ per $100 before August, 1957) of the cash or cash equivalent transferred from the buyer to the seller at the time of sale, plus the face value of the credit extended by the seller to the buyer.

The identity used to determine sale price, Y, by means of the Federal tax stamps was:

$$Y = \frac{\$500 \times \text{Value of Federal stamps}}{\$0.55} - \$250$$

Since many sales are not in even $500 amounts, the $250 adjustment is used to interpolate midway between the maximum and minimum sales prices that could be represented by the Federal stamps.

The identity used to determine sale price, Y, by means of the State stamps for observations transferred before August, 1957 was:

$$Y = \frac{\$100 \times \text{Value of State stamps}}{\$0.10} - \$50$$

and after August, 1957:

$$Y = \frac{\$100 \times \text{Value of State stamps}}{\$0.20} - \$50$$

As with the Federal adjustment of $250, the $50 State adjustment is used to interpolate midway between the maximum and minimum property values that could be represented by the State stamps.

Real property tax assessment records were the best available source of estimates for the value of improvements. In Polk County, the assessment procedure is to assess separately the land and buildings on each site. No attempt has been made to ascertain the degree to which total assessed values (land plus improvements) conformed to actual sale prices, although the regression equations which are subsequently presented can readily be employed for that purpose. Thorough appraisals for sites devoted to pasture were last made in 1953, while many of the sites devoted to citrus were appraised as recently as 1963-64.

Since the intention was to consider only those sales of sites whose prices would reflect a priori the effect of air pollution upon Polk County's cattle and citrus industries, any site transfer was excluded from the analysis if one or more of the following conditions was fulfilled:

(1) If the site was not being used for agricultural purposes at the time of sale.

(2) If the site was shifted to a non-agricultural use immediately after the time of sale. It was assumed that all sales to phosphate companies and known speculators in phosphate land fitted this condition for exclusion.

(3) If a transferred site containing citrus had five acres or less.

(4) If a pasture site transfer had twenty acres or less.

(5) If the form of the deed was anything other than a warranty deed.

(6) If the names of buyers and sellers implied kinship and/or if the sale was not a public sale, i.e., if selling price appeared to contain elements of nonpecuniary considerations. However, if it could be determined that sales between relatives were by public auction, then the sale was included. A total of eight usable observations fell into this latter category.

(7) If only a partial interest was transferred, i.e., if the selling price did not convey undivided ownership of the property. This condition, in addition to requiring the deletion of all fractional interests, also necessitated the exclusion of all transfers in which such interests as mineral rights and water rights were not conveyed.

(8) If personal property such as cattle was transferred along with real property and if this simultaneous transfer was recorded on the same deed.

(9) If information dealing with the site's relevant physical attributes was unavailable.

(10) If the selling price could not be read from the deed.

(11) If the property description was extremely involved. This condition for exclusion was employed simply because the opportunity costs associated with copying the description were too great.

(12) If the assessed value of the site's improvements in the year of sale was more than one-quarter of the observation's sale price.

The original sample of deeds for which information was gathered consisted of 822 observations. However, after application of the above mentioned exclusion conditions, 611 items remained for purpose of analysis. Of these items, 297 had at least some citrus upon them at the time of sale and were thus placed in the citrus category while 314 items were classified as pasture.

II. CONSTRUCTION OF VARIABLES

An attempt was made to gather data for just about every influence which could conceivably affect agricultural land values differentially at a point in time or over a relatively short interval of time. That information which was gathered was sufficient to allow for each and every usable observation the construction of twenty-four discrete and distinct explanatory variables.[2] When various transformations of these distinct variables are taken into account, over fifty different explanatory variables were tested in the pasture and the citrus models. However, those variables which led to inferior regression results as judged by the relevant equation's coefficient of multiple determination and the significance and signs of the coefficients of of the independent variables will not be reported here. The meaning of those variables included in the results to be reported here is explained below.

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[2] The complete listing of these explanatory variables, excluding transformations, is as follows: observed per acre assessed value of improvements in dollars; per acre assessed value in dollars of improvements as deflated by the U.S. Wholesale Price Index; acres; time in months; weighted mean age of citrus in years; percentage down payment; a dichotomous variable for natural damages; acres of citrus; acres of cropland; acres of improved pasture, acres of semi-improved pasture; acres of wasteland; acres of native pasture; U.S. highway road frontage in tenths of miles; unpaved road frontage in tenths of miles; a dichotomous variable indicating whether or not the site in question had even been subject to recorded pollutant fumigations; citrus planted within two years of sale in acres; an urban proximity variable to be discussed in the text's main body; the proportion of time in which the wind from a phosphate plant near the County's southern border blows toward ± 22.5 degrees of the site in question; the arithmetic mean velocity in tenths of miles of the aforementioned wind; the distance in tenths of miles of the site in question from a point in the middle of the area subject to the most severe pollutant fumigations; the proportion of tricalcium phosphate in the phosphate rock underlying a site; and, finally, the frequency in months with which a site was subject to pollutant fumigations.

Dependent variable: citrus and pasture. The dependent variable employed for all regressions was observed per acre sale price in unadjusted dollars.

Independent variables: citrus only. Three explanatory variables are found only in the citrus model. The first of these is X_4, the weighted mean age in years of citrus upon the site at the time of sale. One would expect this variable to be positively related to sale price. In order to avoid having to include variables in the single equation model for each type of citrus found upon each site, the ages of citrus types other than oranges were converted into orange age equivalents. These equivalents were determined by weighting the number of acres of non-oranges (Marsh grapefruit and Duncan grapefruit, including tangerines) of a given age by their present value relative to the present value of oranges of the same age, summing these products for each type of citrus of each age, and then dividing by the total acreage in the site. In notational form,

$$X_4 = \frac{\sum_{i}^{3} \sum_{i}^{60} \left(\frac{w_{ij}}{w_{io}}\right) g_{ij}}{g}$$

where w_{ij} is the present value of i -year old citrus of the jth type, w_{io} is the present value of i -year old citrus of the orange type, g_{ij} is the number of acres of i -year old citrus of the jth type and g is the total number of acres of citrus upon the site. The values for the w terms were obtained from the citrus value table employed by the Polk County Tax Assessor's Office. This table is reproduced as Table XII. Thus the method of calculating the X_4 variable implicitly assumed that the relative values for each age and for all possible sets of ages

TABLE XII

POLK COUNTY TAX ASSESSMENT SCHEDULE
FOR CITRUS AS OF 1964
(REVISED MARCH 12, 1958)

Grove Age in Years	Assessed Value of Oranges	Assessed Value of Marsh Grapefruit	Assessed Value of Duncan Grapefruit
1	$ 300	$ 300	$ 300
2	300	300	300
3	300	300	300
4	400	350	300
5	500	400	350
6	600	450	400
7	700	550	450
8	800	600	500
9	900	750	550
10	1000	800	600
11	1100	900	650
12	1200	950	700
13	1300	1050	750
14	1400	1100	800
15	1500	1200	900
16	1600	1300	950
17	1700	1350	1000
18	1800	1450	1100
19	1900	1500	1150
20+	2000	1600	1200

Source: Polk County Tax Assessor's Office, Bartow, Florida.

within, between, and among the citrus varieties being considered have remained constant throughout the 1947-64 time interval.

The second variable employed only in the citrus equations is X_{27}, a dichotomous variable employed for taking into account those natural damages caused by freezes and frosts, diseases, insects, and other citrus antagonists which have been recorded in the Polk County Tax Assessor's Office. A value of two was assigned to the observation in question if natural damages were severe enough to be recorded on assessment records at any time in the 1947-64 interval. A value of one was assigned if these damages did not appear in the records. Hopefully, this procedure tends to make the relation reasonably sensitive to such factors as topographical advantages, water accessibility, and soil quality. Although it might well have been possible to construct a variable combining the frequency of natural damages with a geometric mean reflecting the severity of each type of natural damage, the investigator at the very beginning of the study did not feel that the gain in precision would be commensurate with the effort which would have to be expended in order to construct such a variable. Final results make this initial supposition appear to be correct. Given the form employed for this variable, one would expect it to be inversely related to observed per acre sale price.

The third and last variable found only in the citrus formulations is X_{39}, a transformed variable assuming a value of one hundred times the proportion of the total acreage in the observation devoted to citrus. Since citrus production is that agricultural use offering the highest net returns in the Polk County area, one would expect, if the site is at all suitable for citrus production, the regression coefficient for this variable to have a positive sign.

Independent variables: pasture only. There are two variables found in the pasture regressions which are not found in the citrus regressions. The first of these is an urban proximity index, X_{24}.[3] In notational form this variable is equivalent to $\sum_{i=1}^{3} (Pi/Di)$ where Pi is the population in the nearest census year of the ith town, and Di is the straight-line distance in miles of the site from this same town. One would expect that for a given distance, the greater the populations of the towns or cities closest to a site, the greater the value of the site. Similarly, for given populations of the towns closest to the site, the farther the site from the towns or cities the less the value of the site. Thus tne X_{24} variable can be expected to vary directly with observed per acre sale price. Table XIII gives the 1940, 1950, and the 1960 census figures for all towns and cities employed in the construction of the X_{24} variable.

In the form in which it has been constructed, the X_{24} variable is as simple-minded a variable as could possibly be employed. Among other things, it assumes that site values decrease linearly with straight-line distance and, even worse, it assumes that site values change linearly with the population of up to five years before or after the observation's time of sale. Though attempts were made to get yearly population estimates, yearly retail sales estimates, estimates of yearly building permits issued, total assessed valuations of real property for each

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[3] This variable was tested in the citrus equations and for the sample at hand found to be statistically nonsignificant. One factor which may contribute to this lack of significance is the practice of assessing agricultural properties for tax purposes on the basis of their present use only. As one possible result of this practice, one becomes accustomed to seeing fairly large citrus groves in the midst of quite densely populated incorporated areas. For the law justifying this assessment practice, see Florida Statute 193.11(3)

TABLE XIII

POPULATIONS OF POLK COUNTY CITIES AND TOWNS

Town	1940 Population	1950 Population	1960 Population
Auburndale	2,723	3,763	5,595
Bartow	6,158	8,694	12,849
Davenport	640	760	1,209
Dundee Lake Hamilton	1,038	1,756	2,484
Fort Meade	1,992	2,803	4,014
Frostproof	1,704	2,329	2,664
Haines City	3,890	5,630	9,135
Lake Alfred	920	1,270	2.191
Lakeland	22,068	30,851	41,350
Lake Wales	5,024	6,821	8,346
Mulberry	1,502	2,024	2,922
Plant City[a]	7,491	9,230	15,711
Polk City	195	171	203
Winter Haven	6,199	8,605	16,277

[a] Plant City is just over the western border of Polk County in Hillsborough County. It is the only town of any appreciable size outside Polk County that is located closer to some of the observations in the study than are the Polk County towns and cities of similar size.

Source: U.S. Bureau of the Census, County and City Data Book (Washington, D.C.: U.S. Govt. Printing Office, relevant years.)

year, and a host of other potential measures of the relative economic viability of each town, all such attempts had at best only partial and therefore inadequate success.[4] As for the linear relations assumed between site value and distance, and site value and population, various powers of Pi and Di were regressed against site value. The best results were obtained with the simple linear form employed here.

The second variable employed only for the pasture regressions is X_{36}, the arithmetic sum of the number of acres of wasteland and the number of acres of native pasture. Found in the wasteland category are swamps, marshes and scrubland in which is included forest, lakes, and so-called hummocks. The native pasture category is simply land covered with local, unfertilized grasses. Since perhaps except for abandoned phosphate mine pits and mine tallings, these categories offer the lowest net returns of any Polk County agricultural or nonagricultural land use, one can reasonably expect the signs for the regression coefficients of the X_{36} variable to be negative. In addition, since the proportion of a site in wasteland and/or native pasture tends to be highly and positively correlated with the number of acres in the site, the extent to which the coefficient of the X_{36} variable measures the negative impact of wasteland and/or native pasture upon per acre site value tends to be confounded by the effect of absolute site size upon this same value.[5] The sign of the actual relation between site size and per acre site value cannot of course be known *a priori*, but unless one insists that substantial economies of scale are associated with increased pasture acreage, the assumption of no relation or of a negative relation does not appear unreasonable.

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[4] Given the obvious importance of Lakeland in the area's economy, complete information from every other town or city would be of no use unless similar information was available for Lakeland. Attempts to obtain information from this latter city met with no success whatsoever.

[5] The simple correlation coefficient for all pasture sites in the sample between the proportion of the site in wasteland and/or native pasture and the absolute size in acres of the site is .932.

Independent variables: pasture and citrus. There are three variables common to the pasture and to the citrus regression models. The first of these variables is X_1, the observed per acre assessed value of improvements upon the site at the time of sale. Values for this variable were taken directly from material in the Polk County Tax Assessor's Office. Since, in nearly all conceivable circumstances, a given site with an improvement would be more valuable than the same site without the improvement, one would expect the regression coefficients for this variable to have positive signs.

The second variable which the pasture and citrus models have in common is the X_{42} variable, a variable defining the quality of phosphate ore underlying the site in question and a variable which could take on only four values: 1, 63, 70 and 74. The first of these values indicates that there is no phosphate ore of any apparent economic value underlying the site in question, while the latter three values indicate the B. P. L. or bone phosphate of lime content of the phosphate ore underlying a site.[6] Everything else being equal, the higher the B.P.L. content of a given body of ore, the more valuable is the body of ore because the ore will then have a greater P_2O_5 content. The P_2O_5 is of course that nutrient for whose extraction and concentration the whole phosphate fertilizer industry exists. The sources employed for calculation of the X_{43} variable were a 1939 map purporting to show the areal distribution of B.P.L. in phosphate ore throughout Polk County,[7] and a 1963 map which supposedly shows that portion of the Polk County phosphate ore body which is "economic."[8] Bone phosphate of lime values greater than one were assigned only to those observations lying within the "economic" calcium phosphate zone.

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[6] In the phosphate mining and processing industry, B.P.L. is commonly used to refer to the ore's proportionate tricalcium phosphate or $Ca_3(PO_4)_2$ content by weight. The equivalent in phosphorus pentoxide or P_2O_5 can be obtained by multiplying the B.P.L. value by a factor of 0.6319. See U.S. Department of Agriculture, and Tennessee Valley Authority, *Superphosphate: Its History, Chemistry, and Manufacture*, (Wash. D.C.: U.S. Govt. Printing Office, Dec.1964) pp. 5-7.

The third variable which the pasture and citrus regressions have in common is X_{43}, a variable intended to measure the intensity with which a given site has been subjected to pollutant fumigations. The regression coefficients assumed by this variable are of course the major interest in this study. The sole reason we even bother to include all the other independent variables is to separate the influence of air pollution upon per acre site value from other factors which influence site value. Our hypothesis then states, ceteris paribus, that the greater the intensity of the air pollution to which a given site is subject, the less is its per acre site value. Our immediate purpose is to test this hypothesis by means of a single equation, cross-sectional multiple regression study of citrus land values and of pasture land values in Polk County, Florida. If the least squares estimates of the single equation, cross-sectional regression models are unbiased, consistent, and efficient, and if the regression coefficients for the X_{43} variable prove to have a negative sign and to be statistically significant, then we can fail to reject the hypothesis.

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[7] George R. Mansfield, Phosphate Resources of Florida, U.S. Geological Survey, Bull. 934, (Wash., D.C.: U.S. Govt. Printing Office, 1942) Plate 5.

[8] James B. Cathcart, Economic Geology of the Fort Meade Quadrangle, Polk and Hardee Counties, Florida, U.S. Geological Survey, Bull, 1207, (Wash. D. C.: U. S. Govt. Printing Office, 1966), p.3.

The X_{43} variable as employed here makes the assumption that the frequency with which a site is subjected to a given level of pollution is synonymous with or is at least directly and proportionately related to the intensity with which the given site has been subjected to pollutant fumigations.[9] More specifically, it is assumed that at any one point in time from September, 1947, through July, 1964, the intensity of fluoride air pollution in Polk County, Florida is equivalent to or is at least a function of ten times the number of months in the thirty-three month interval from April, 1961, to December, 1963, in which pasture grasses upon the sites in question did or would have accumulated over a twenty-eight day period fluorides on a dry weight basis equal to or in excess of forty parts per million.[10] Given that the values assumed by relevant meteorological parameters over individual two to three year periods in the 1947-64 interval did not differ greatly from the values assumed by these parameters in the 1961-63 interval, the form of the X_{43} variable employed here can be expected to give a reasonable representation of the intensity of pollution suffered by any one site for various volumes and rates of fluoride emissions. In essence, the X_{43} variable is a measure which collapses a multitude of relevant meteorological and emission parameters, most of which are poorly understood, into a single index. All that is necessary for the index to be a good indicator of emission levels throughout the 1947-64 period is that the values assumed by meteorological parameters in 1961-63 be similar to those in other years. If this similarity exists, then the impact of pollution upon land values will vary directly with the absolute level of emissions in any single two or three year period. Or, even if the values assumed by meteorological parameters throughout the whole period do not resemble those of 1961-63, the implications about the impact of various emission levels upon relative land values in any two or three year cross section will not change so long as the pollutant concentrations upon each and every site in the sample change in direct proportion to the changes in the values assumed by the meteorological parameters.

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[9] A measure of simple frequency or rate may represent only one aspect of intensity. The cumulative volume and/or the interval of time over which a given rate occurs may be just as or even more important than rate.

[10] The State of Florida specifies that the samples from which these concentrations are determined shall be analyzed in the following manner. "Fluorine content shall be determined from unwashed samples. The average background for natural forage from an uncontaminated area shall be subtracted from the values obtained." Should the adjusted sample contain more than forty and less than eight ppm, the fluorine content is established by determining the content of washed samples, then determining the content in the solution used to wash the samples, and, finally, calculating the available fluorine on the basis of one part of the washed sample plus one-half of the content found in the washing material. Cf. Rules of the Florida Air Pollution Control Commission, Chap. 28-2, 1, 5 (Jan. 20, 1965). The writer is indebted to the Florida State Board of Health for making the records of these samples available to him.

Finally, the writer did have available to him data severely limited in both quality and quantity which gave a five year time series on wind velocities and directions from three geographical points in the Polk County area. However, it seems poor research strategy to attempt to construct a multiple source micrometeorological model which will serve as an accurate proxy for pollutant concentrations when fairly adequate data on pollutant concentrations is already available. First, it is questionable that an accurate model could be constructed, for micrometeorological theorists are as enamoured of flat, featureless plains as are economic location theorists.[11] Second, knowledge about meteorological parameters is useful only if one wishes to forecast the pollutant concentrations resulting from various levels of pollutant emissions. The immediate interest here is in determining the causal relation, if any, between pollutant concentrations and differential land values. We can safely assume that these concentrations are directly related to the level of pollutant emissions without devoting explicit attention to the physical medium through which they are made to be related.[12]

III. THE REGRESSION MODELS

As previously noted, the models employed here are single equation, cross-sectional multiple regression models to be analyzed by traditional least squares techniques. Separate models are employed for pasture and for citrus. These models were applied to two and three year partitions of the pasture observations and the citrus observations. A year by year breakdown from 1947 through 1964 of the arithmetic means and the standard deviations for the original values of each variable included in all pasture and citrus estimating equations to be reported here is presented in Tables XIV and XV. For purposes of comparison, the means and standard deviations of all variables for each of the partitions by years employed in the estimating equations are presented in Tables XVI and XVII.

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[11] Furthermore, existing multiple source micrometeorological models are few and far between. Most conceptual and empirical work has considered only single point sources. For an interesting attempt at construction of a multiple source model in a complex urban situation, see D. Bruce Turner, "A Diffusion Model for an Urban Area," Journal of Applied Meteorology, 3 (Feb., 1964), pp. 83-91.

[12] Recent evidence suggests that the Polk County micrometerological situation may be more involved than has commonly been supposed. Apparently

Several alternative models were tested in preliminary regressions but the best results were obtained for pasture with a model linear in the original values of the variables. Thus, in notational form, the basic pasture regression equation is:

IP. $Y_1 = a + b_1 X_1 + b_{24} X_{24} + b_{36} X_{36} + b_{42} X_{42} + b_{43} X_{43} + E$,

where a is an intercept term and where E is assumed to be a normally distributed random variable with zero mean and finite variance. Table XIX presents the regression results of the application of this single equation model to the Polk County pasture value data.

For the citrus regression, the basic equation is linear in the logarithms of the original values of the variables, with the exception of the values for the X_1 or improvement variable entering linearly in the variable's original values.[13] Thus, in notational form, the basic citrus estimating equation is:

IC. $\log Y = \log a + b_4 \log X_4 + b_{27} \log X_{27} + b_{39} \log X_{39} + b_{43} \log X_{43} + \log E + b_1 X_1$,

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there exists a complex vertical rolling and/or horizontal rotation of the air mass so that some air moving toward the northeast into which fluorides are emitted ultimately turns around to return in the same direction from which it came. Thus a single receptor site could conceivably have the same fluoride bearing air mass pass over it several times. See Polk-Hillsborough Air Pollution Control District, Annual Activities Report: 1966, (Winter Haven, Florida.: Florida State Board of Health, March 17, 1967), pp. 5-9. (Mimeographed.)

[13] It was necessary to have the values for the X_1 variable enter linearly in the variable's original values because some of these original values were zero.

TABLE XIV

CITRUS: MEANS AND STANDARD DEVIATIONS BY YEARS

Variable Year and Statistics		Y_1	X_4	X_{27}	X_{39}	X_{42}	X_{43}	X_1	Sample Size
1947	Mean	564.14	18.68	1.40	45.65	70.00	25.25	31.95	4
	S.D.	567.39	18.85	.55	28.74		24.20	43.81	
1948	Mean	318.75	8.25	1.25	100.00	1.00	1.00		4
	S.D.	229.57	11.30	.50					
1949	Mean	632.08	13.30	1.42	82.50	45.83	15.58	1.71	12
	S.D.	557.60	8.82	.51	12.44	31.80	27.53	5.93	
1950	Mean	429.96	8.87	1.53	65.31	26.69	8.13	1.25	16
	S.D.	312.62	7.16	.52	39.87	33.22	10.47	4.82	
1951	Mean	695.77	12.96	1.50	48.34	37.62	10.62	17.03	12
	S.D.	726.34	9.54	.52	52.66	33.95	14.26	45.10	
1952	Mean	883.33	7.57	1.33	30.48	47.00	13.67		4
	S.D.	765.40	2.89	.58	64.31	32.53	8.96		
1953	Mean	739.32	16.82	1.50	85.18	10.64	1.64	23.69	14
	S.D.	581.88	10.57	.52	16.03	23.71	2.32	63.00	
1954	Mean	845.22	15.94	1.37	61.18	19.78	10.22	.52	18
	S.D.	724.52	11.81	.50	42.47	30.31	18.61	1.63	
1955	Mean	1,273.87	11.72	1.55	78.89	18.25	1.00	9.01	11
	S.D.	1,248.16	11.20	.52	26.52	29.88		20.67	

TABLE XIV

(CONTINUED)

Variable Year and Statistics		Y_1	X_4	X_{27}	X_{39}	X_{42}	X_{43}	X_1	Sample Size
1956	Mean	1,043.43	19.56	1.63	70.17	26.05	14.84	4.34	19
	S.D.	854.14	10.73	.50	33.19	32.84	42.16	15.90	
1957	Mean	809.93	10.48	1.36	65.19	35.18	17.27	29.08	22
	S.D.	685.69	9.43	.49	34.97	34.21	34.67	107.14	
1958	Mean	1,230.88	16.67	1.44	81.44	34.33	16.72	20.51	19
	S.D.	918.72	12.63	.51	18.26	33.41	32.95	76.12	
1959	Mean	1,572.36	13.18	1.34	65.57	29.94	14.52	109.62	31
	S.D.	1,293.75	11.32	.48	34.86	34.05	34.88	332.27	
1960	Mean	1,514.70	15.96	1.09	78.93	13.55	14.55	22.01	11
	S.D.	1,176.32	13.43	..30	21.45	26.61	31.21	45.79	
1961	Mean	1,350.16	13.41	1.43	43.08	33.38	16.19	104.51	21
	S.D.	1,074.48	11.54	.51	57.13	34.03	34.24	280.25	
1962	Mean	1,596.50	19.46	1.37	69.78	27.44	18.50	45.88	19
	S.D.	1,213.60	13.09	.50	31.09	33.19	33.57	95.29	
1963	Mean	2,332.19	22.32	1.32	64.15	24.49	14.27	59.13	38
	S.D.	1,609.98	12.41	.47	36.81	31.97	27.94	167.59	
1964	Mean	1,788.24	19.09	1.48	67.26	32.78	12.00	38.32	22
	S.D.	1,438.77	12.43	.51	34.73	33.28	28.30	114.16	

TABLE XV

PASTURE: MEANS AND STANDARD DEVIATIONS BY YEARS

Variable Year and Statistics	Y_1	X_1	X_{24}	X_{36}	X_{42}	X_{43}	Sample Size
1947 Mean	21.45		677.60	583.40	22.56	4.00	18
S.D.	23.12		728.27	983.69	31.98	8.13	
1948 Mean	59.22	.89	1,241.71	90.21	39.43	14.38	21
S.D.	76.57	2.98	980.33	96.64	33.36	20.90	
1949 Mean	41.18	.02	1,521.87	282.54	43.69	21.19	13
S.D.	36.29	.07	1,349.03	718.51	33.11	29.29	
1950 Mean	34.85	3.00	896.83	152.85	35.59	11.51	39
S.D.	43.07	17.16	1,069.01	735.89	32.88	18.41	
1951 Mean	63.99	1.68	1,158.09	360.32	40.36	9.91	22
S.D.	59.35	5.72	1,094.17	753.21	35.42	26.37	
1952 Mean	65.06	1.78	1,078.47	36.01	54.80	15.87	16
S.D.	38.05	6.67	758.10	52.65	27.04	19.89	
1953 Mean	124.29	.13	2,162.58	27.84	70.57	44.29	8
S.D.	67.37	.29	1,510.10	48.83	1.40	25.56	
1954 Mean	87.67	.73	1,107.04	118.82	33.09	5.61	22
S.D.	61.74	2.53	1,085.71	346.34	33.85	10.62	
1955 Mean	109.43	.09	2,330.18	57.60	32.85	12.31	13
S.D.	71.26	.33	3,616.89	70.66	34.40	23.11	

TABLE XV

(CONTINUED)

Variable Year and Statistics		Y_1	X_1	X_{24}	X_{36}	X_{42}	X_{43}	Sample Size
1956	Mean	237.93	50.91	1,226.67	603.50	61.71	25.76	15
	S.D.	223.67	111.94	1,375.17	2,074.98	22.25	34.32	
1957	Mean	359.07	51.60	2,280.61	145.16	35.50	18.25	14
	S.D.	315.85	105.00	2,374.83	292.01	34.50	27.62	
1958	Mean	196.30	84.17	1,719.66	84.17	22.83	17.50	7
	S.D.	235.59	131.42	1,112.26	95.02	30.94	36.90	
1959	Mean	335.74	111.82	1,483.95	58.85	39.93	21.36	13
	S.D.	334.31	262.51	1,213.02	132.31	33.76	32.65	
1960	Mean	135.11	.22	1,469.01	307.96	49.73	11.40	15
	S.D.	92.97	.73	1,692.05	371.80	29.53	20.76	
1961	Mean	282.10	1.30	1,143.81	419.55	36.29	16.59	19
	S.D.	238.49	2.89	1,295.67	1,000.71	33.62	25.71	
1962	Mean	359.22	99.78	3,336.33	107.84	41.64	20.64	20
	S.D.	412.95	347.33	7,042.57	249.26	33.85	30.93	
1963	Mean	173.14	18.87	1,513.05	383.48	21.68	8.79	19
	S.D.	134.40	80.08	1,268.57	710.74	30.51	25.39	
1964	Mean	311.40	22.07	1,442.09	402.92	41.35	10.30	20
	S.D.	310.61	54.87	1,399.43	842.63	33.03	22.35	

TABLE XVI

CITRUS: MEANS AND STANDARD DEVIATIONS BY GROUPS OF YEARS

Variable Years and Statistics		Y_1	X_4	X_{27}	X_{39}	X_{42}	X_{43}	X_1	Sample Size
1947-50	Mean	499.89	11.37	1.45	72.71	35.03	11.82	5.99	36
	S.D.	413.36	9.47	.52	25.06	25.36	16.52	8.99	
1951-53	Mean	741.10	14.04	1.48	63.15	26.28	6.84	17.87	31
	S.D.	664.13	9.13	.53	34.87	28.98	7.98	47.44	
1954-46	Mean	1,001.06	16.07	1.48	67.39	21.46	9.73	3.90	49
	S.D.	877.54	11.01	.50	34.42	30.58	23.18	11.40	
1957-58	Mean	1,030.13	13.68	1.43	74.54	34.79	17.02	25.11	40
	S.D.	812.62	11.19	.50	27.91	33.84	33.87	92.76	
1959-60	Mean	1,557.26	13.91	1.27	69.07	25.65	14.53	86.67	42
	S.D.	1,262.99	11.87	.43	31.35	32.10	33.92	257.24	
1961-62	Mean	1,467.17	16.28	1.40	55.76	30.56	17.29	76.66	39
	S.D.	1,140.56	12.28	.51	44.76	33.63	33.92	192.39	
1963-64	Mean	2,131.08	21.14	1.38	65.29	27.53	13.44	51.50	60
	S.D.	1,547.20	12.42	.48	36.05	32.45	28.07	148.00	

TABLE XVII

PASTURE: MEANS AND STANDARD DEVIATIONS BY GROUPS OF YEARS

Variable Years and Statistics		Y_1	X_1	X_{24}	X_{36}	X_{42}	X_{43}	Sample Size
1947-49	Mean	42.99	.37	1,172.73	300.95	36.29	13.54	52
	S.D.	56.82	1.96	1,111.18	715.55	34.34	22.67	
1950-51	Mean	45.36	2.52	991.06	227.68	37.31	10.93	61
	S.D.	53.02	14.28	951.72	520.46	33.83	21.60	
1952-54	Mean	84.18	.96	1,240.49	77.56	45.17	14.74	46
	S.D.	62.65	4.30	1,148.55	253.86	32.71	21.77	
1955-57	Mean	232.77	35.38	1,869.36	303.57	45.29	19.45	42
	S.D.	247.09	94.84	2,621.22	1,369.52	33.43	30.23	
1958-60	Mean	225.85	59.25	1,517.95	169.95	41.20	16.43	35
	S.D.	261.51	184.96	1,447.76	290.81	33.39	29.84	
1961-62	Mean	325.78	56.85	2,380.62	243.71	39.31	18.87	39
	S.D.	354.52	268.87	5,538.83	713.09	34.19	29.22	
1963-64	Mean	244.04	20.51	1,476.66	393.45	31.77	9.56	39
	S.D.	254.29	69.23	1,355.24	791.44	33.75	24.21	

TABLE XVIII

CITRUS: REGRESSION RESULTS FOR EQUATION IC

Equation Form: $\log Y_1 = \log a + b_4 \log X_4 + b_{27} \log X_{27} + b_{39} \log X_{39} + b_{43} \log X_{43} + \log E + b_1 X_1$

Year Groupings		n=36	n=31	n=49	n=40	n=42	n=39	n=60
Coefficients and Statistics		1947-50	1951-53	1954-56	1957-58	1959-60	1961-62	1963-64
Intercept:	a	4.693^a	1.767^b	2.773^a	4.220^a	3.702^a	4.311^a	3.661^a
Regression Coefficients:	b_4	$.595^a$ (.103)	$.457^a$ (.120)	$.415^a$ (.086)	$.387^a$ (.107)	$.506^a$ (.073)	$.710^a$ (.095)	$.576^a$ (.089)
	b_{27}	$-.869^b$ (.362)	$-.817^b$ (.364)	-1.308^a (.286)	-.643 (.434)	$-.750^a$ (.276)	-1.303^a (.294)	-1.183^a (.222)
	b_{39}	.117 (.254)	$.824^a$ (.133)	$.707^a$ (.227)	.419 (.332)	$.518^a$ (.129)	$.336^a$ (.095)	$.576^a$ (.100)
	b_{43}	.009 (.101)	.043 (.091)	-.069 (.042)	$-.086^b$ (.039)	$-.113^a$ (.040)	$-.174^a$ (.057)	.002 (.047)
	b_1	-.007 (.007)	$.008^b$ (.003)	$.007^b$ (.007)	$.001^b$ (.0004)	$.001^b$ (.0004)	$.001^b$ (.0004)	-.0005 (.001)

TABLE XVIII

(CONTINUED)

Year Groupings	n=36	n=31	n=49	n=40	n=42	n=39	n=60
Coefficients and Statistics	1947-50	1951-53	1954-56	1957-58	1959-60	1961-62	1963-64
Coefficient of Multiple Determination	.729	.829	.824	.756	.877	.892	.810
Standard Error of Regression Equation	.685	.671	.648	.779	.523	.526	.537
F Ratio	7.502[d]	10.978[d]	16.155[d]	5.126[d]	23.217[d]	25.672[d]	20.556[d]

[a] Denotes significance at the .01 level of the t- distribution.

[b] Denotes significance at the .05 level of the t- distribution.

[c] Denotes significance at the .10 level of the t- distribution.

[d] Denotes significance at the .01 level of the F- distribution.

The figures in parentheses are the standard errors of regression coefficients.

TABLE XIX

PASTURE: REGRESSION RESULTS FOR EQUATION IP

Equation Form: $Y_1 = a + b_1X_1 + b_{24}X_{24} + b_{36}X_{36} + b_{42}X_{42} + b_{43}X_{43} + E$

Year Groupings		n=52	n=61	n=46	n=42	n=35	n=39	n=39
Coefficients and Statistics		1947-49	1950-51	1952-54	1955-57	1958-60	1961-62	1963-64
Intercept:	a	27.086	21.934	75.903	172.428	158.767	278.168	220.662
Regression Coefficients:	b_1	2.706^a (.312)	2.205^a (.358)	1.766^a (.442)	1.526^a (.343)	1.179^a (.138)	1.003^a (.133)	$.849^c$ (.463)
	b_{24}	$.007^b$ (.003)	$.015^b$ (.006)	$.012^c$ (.007)	$.010^b$ (.004)	0.000 (0.000)	-.011 (.009)	$.027^b$ (.010)
	b_{36}	-.011 (.007)	-.007 (.008)	$-.007^b$ (.003)	$-.027^c$ (.014)	$-.142^b$ (.069)	-.063 (.042)	-.026 (.036)
	b_{42}	.034 (.179)	.069 (.167)	$.611^b$ (.293)	$.726^a$ (.209)	$.524^a$ (.178)	$.888^b$ (.343)	-.762 (1.501)
	b_{43}	.177 (.302)	.201 (.273)	1.370^a (.460)	-1.908^b (.774)	$.744^b$ (.296)	3.957^a (.889)	.038 (1.927)

TABLE XIX

(CONTINUED)

Year Groupings	n=52	n=61	n=46	n=42	n=35	n=39	n=39
Coefficients and Statistics	1947-49	1950-51	1952-54	1955-57	1958-60	1961-62	1963-64
Coefficient of Multiple Determination	.790	.730	.765	.846	.885	.829	.436
Standard Error of Regression Equation	36.306	37.591	54.819	149.824	129.859	212.859	257.111
F Ratio	19.274[d]	15.638[d]	13.574[d]	15.150[d]	20.934[d]	14.482[d]	.840

[a] Denotes significance at the .01 level of the t- distribution.

[b] Denotes significance at the .05 level of the t- distribution.

[c] Denotes significance at the .10 level of the t- distribution.

[d] Denotes significance at the .01 level of the F- distribution.

The figures in parentheses are the standard errors of the regression coefficients.

where a is an intercept term and where it is assumed that E is log-normally distributed with a mean of unity and with finite variance. Table XVIII presents the regression results of this model when applied to the Polk County citrus land value data.

IV. SOME CONSIDERATIONS

Before going any further, it is perhaps worthwhile to discuss and hopefully negate the major bases upon which the results presented in Tables XVIII and XIX might be attacked, for given what has been presented up to this point there are several levels and dimensions at which attacks might justifiably be made.

The first point at which one might thrust is a point upon which any study depending on cross-sectional analysis alone can be criticized: the necessity of compromising between having samples of a size adequate for estimation purposes and maintaining that premise of a perfect randomness of temporal variability which underlies all cross-sectional analysis. Thus, even though any measurement errors in the explanatory variables are not highly correlated with each other or with the true values of the explanatory variables, the possibility of least-squares bias still arises in that for any single cross-section the relation being estimated may have shifted over that cross-section's time interval. And, of course, the longer the time interval encompassed within an individual cross-section, the greater the likelihood such shifts have taken place. If one wishes, he could of course carry the argument to ridiculous lengths by insisting that any cross-section, no matter how short, must involve some nonrandom time variability. To disprove such a contention in any empirical situation would be highly troublesome, for the only manner in which one could do it would be by specifying and

and identifying all the world's relations or by partitioning the cross-section in time over an infinite number of time intervals. Here, in Tables XX and XXI, is presented for the pasture observations and for the citrus observations of Equations IP and IC only two of the infinite number of alternative partitions of the September 1, 1947 - July 31, 1964 interval. Since the coefficients of the X_{43} or frequency of pollutant fumigations variable are the items of major interest in this study, only the results for that variable are set forth. As the reader will note, the magnitudes of the coefficients do change from partition to partition, but, most important for our purposes, the temporal pattern of the signs and magnitudes of the coefficients for the partitions in Tables XX and XXI does not differ substantially from the partitions employed in Tables XVIII and XIX.[14] One might therefore conclude that the temporal pattern of the coefficient's signs and their approximate magnitudes will remain the same regardless of the partitions performed upon the 1947-64 interval.

However, if one is interested in the effects that fluoride air pollution has had upon the citrus and the beef cattle industries of Polk County, the use of cross-sectional analysis raises problems no matter what the lack of temporal variability in any one cross-section. Initially, given that differential land values do accurately reflect differences in the present values of expected future net returns as between and among sites, the writer's intention amounted to nothing

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[14] A much superior alternative to the comparison of various partitions in order to discern the impact of nonrandom time variability within the same cross-section is the acquisition of more observations. Thus, for a given sample size, the time interval to which it applies can be contracted. Relatively few additional usable observations were available in the Polk County universe however.

TABLE XX

REGRESSION COEFFICIENTS AND STANDARD ERRORS OF THE X_{43} VARIABLE FOR EQUATION IP UNDER ALTERNATIVE PARTITIONS OF THE 1947-64 INTERVAL

	Partition #1		
Time Interval	b_{43}	S.E.	n
Sept., 1947 - Sept., 1948	.105	.329	33
Oct., 1948 - Apr., 1950	.278	.356	32
May, 1950 - Feb., 1951	.196	.149	33
Mar., 1951 - Oct., 1952	.446	.387	33
Jan., 1953 - Jan., 1955	1.512^a	.474	33
Feb., 1955 - Sept., 1957	-1.909^b	.812	33
Oct., 1957 - Oct., 1960	$.631^b$	.302	31
Nov., 1960 - July, 1962	2.76[illegible]^a	.964	33
Aug., 1962 - July, 1963	4.512^a	1.030	29
Aug., 1963 - July, 1964	.258	2.139	24

	Partition #2		
Time Interval	b_{43}	S.E.	n
Sept., 1947 - Feb., 1949	.194	.326	43
Mar., 1949 - Nov., 1950	.182	.267	33
Dec., 1950 - Aug., 1951	.376	.319	39
Jan., 1952 - May, 1954	1.217	.868	32
June, 1954 - July, 1956	-2.412^a	.746	33
Aug., 1956 - Aug., 1959	$.705^a$	.266	33
Sept., 1959 - Oct., 1961	1.628^a	.582	34
Dec., 1961 - Feb., 1963	4.195^a	.916	35
Mar., 1963 - July, 1964	.174	1.739	32

[a] Denotes significance at the .ol level of the t- distribution.

[b] Denotes significance at the .05 level of the t- distribution.

[c] Denotes significance at the .10 level of the t- distribution.

TABLE XXI

COEFFICIENTS AND STANDARD ERRORS OF THE X_{43} VARIABLE FOR EQUATION IC UNDER ALTERNATIVE PARTITIONS OF THE 1947-64 INTERVAL

Partition #1

Time Interval	b_{43}	S.E.	n
Spet., 1947 - Apr., 1950	.009	.087	30
May, 1950 - Oct., 1953	.211	.190	32
Dec., 1953 - Sept., 1955	-.051	.098	34
Feb., 1956 - June, 1957	-.043	.035	32
July, 1957 - Feb., 1959	-.115[c]	.066	33
Mar., 1959 - Oct., 1960	-.130[c]	.072	33
Dec., 1960 - July, 1962	-.243[a]	.061	35
Aug., 1962 - Sept., 1963	-.060	.039	34
Oct., 1963 - June, 1964	.029	.201	34

Partition #2

Time Interval	b_{43}	S.E.	n
Sept., 1947 - Jan., 1951	.008	.141	38
Feb., 1951 - May, 1954	.074	-.165	35
June, 1954 - Mar., 1956	-.056[b]	.062	35
Sept., 1956 - May, 1958	-.073[b]	.034	34
June, 1958 - June, 1959	-.106[b]	.042	36
July, 1959 - June, 1961	-.132[a]	.045	34
July, 1961 - Apr., 1963	-.198[a]	.053	35
May, 1963 - June, 1964	.037	.461	50

[a] Denotes significance at the .01 level of the t- distribution.

[b] Denotes significance at the .05 level of the t- distribution.

[c] Denotes significance at the .10 level of the t- distribution.

more than to use the land value data as a means of measuring the impact of fluoride air pollution upon the relative values of various sites for the production of citrus and beef cattle. Since one would expect, *ceteris paribus*, an inverse relation between frequency of pollutant fumigations and site values, it was expected that the land value study would give a reasonable approximation of the damages actually imposed on citrus and beef cattle production--at least for those receptors who had actually placed their sites upon the market and had sold them. Though the citrus results appear to have at least partially fulfilled the original objective, the pasture results have clearly failed to do so. That is, even within a single cross-section the pasture results do not give an indication of the economic damages in the Polk County setting that fluoride air pollution does to beef cattle. In other words, if one decided for some odd reason to start a cattle farm in the middle of that Polk County area which has historically been subject to the heaviest pollutant fumigations, the results of this study give one little if any assistance in determining the extent to which air pollution reduces the productivity of that location relative to other locations for the raising of beef cattle. On an *a priori* basis, one expects the relation between per acre value for pasture and frequency of pollutant fumigations to be inverse. Yet with the exception of one three-year period, it appears to be a direct relation. The explanation of this seeming contradiction even for a single cross-section will require recourse to phenomena which exhibit time variability.[15]

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[15] Of course, any attempt to compare two or more cross-sections requires that one make the comparison in terms of or on the basis of some phenomenon which varies through time. Thus, for example, for both the citrus and the pasture models explanations of differences from one set of years to another in the magnitude of the coefficients for the

To reiterate the previous paragraph, in any econometric study the variables employed can assume any one of three different temporal and areal forms. First, in terms of those employed in this study, there are variables such as the quality of phosphate ore underlying a site which differs among sample sites at any point in time but which remain constant for all intents and purposes through time. In a straightforward cross-sectional analysis this type of variable which exhibits areal variability but temporal stability would be the only type of variable employed. Second, there are the variables such as the expected market price of Marsh seedless grapefruit which are essentially constant between and among sample sites at a point in time but which are subject to change over time. These variables in which there is temporal variability and areal constancy are the types typically employed in time-series analysis. To the extent that such changes have had no substantial differential impact upon Polk County land values over time intervals of three years or less, these changes have no relevance to or impact upon the individual cross-sections in this study. Furthermore, if they affect the value of all similar individual sample parcels in substantially the same manner over time, they have no impact upon differential land values as between and among these similar individual sample parcels. In Polk County there is no reason to think that these "time-section" phenomena have not affected similar parcels in a similar manner. We will thus abstract completely from their effects.

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pollution variable require, among other things, recourse to the temporal path followed by the volume of emissions from the phosphate plants. But for the pasture models, the sign and magnitude of the coefficient for the X_{43} or pollution variable cannot even be explained for a single cross-section without recourse to a phenomenon variable in time.

The third type of variable with which one must deal in any econometric analysis is that type such as the weighted mean age of citrus or the frequency with which a site is subjected to pollutant fumigations which differs between and among sample sites at a point in time and which also differs at different points in time. That is, the variable exhibits both temporal variability and areal variability. The cross-sections presented here hopefully reflect these areal differences reasonably well, but individually they are completely insensitive to the temporal differences. The factors which conceivably could reflect this type of temporal difference are the annual volume of atmospheric fluoride emissions from the phosphate plants, changing views of the courts and the state authorities with respect to the supposed seriousness of the Polk County air pollution problem, expectations of receptor site owners about the frequency with which they will suffer pollution damages, changes in air pollution control technology and phosphatic fertilizer production processes, and a whole host of other factors, including the interactions between and among these factors.

As a perusal of nearly any contemporary economic journal will attest, these variables which are both temporally and areally variable are often taken into account, either directly or by means of a proxy or a set of proxies.[16] However, in the analysis to be presented here, the investigator has been unable to discover suitable proxies which will reflect only the influence upon the posited relations of pressures from the courts and the state authorities upon the phosphate companies to reduce emissions. Thus even though it is the temporal aspect of this third type of variable which will be the key factor in the explanation of the results of the statistical analysis, no attempt is directly made to quantify the aspect in a manner which would render the variable suitable for a pooled time-series, cross-sectional analysis. To do otherwise would be to pretend that a degree of precision exists which is really lacking. Instead, an attempt is made to carry through the analysis by recourse to personal knowledge of the temporal distribution of various actions by the state authorities, the courts, the phosphate companies, and the receptors, and the impact according to economic theory which one can reasonably expect these actions to have upon differential land values. That is, the differences in the regression coefficients of the pollution variable from cross-section to cross-section and the magnitude and sign of the pollution variable's regression coefficient within any single cross-section are attributed to various actions taken by some or all of the aforementioned parties. However, in no case was it possible to measure explicitly the response of the pollution coefficients to these various actions. The explanation provided is plausible and even highly probable but not certain.

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[16] Cf. C. T. Brehm and T. R. Saving, "The Demand for General Assistance Payments," The American Economic Review, 54 (Dec., 1964), 1002-1018; and Edwin Kuh, "The Validity of Cross-Sectionally Estimated Behavior Equations in Time Series Applications," Econometrica, 27 (April, 1959), pp. 197-218.

Yet another aspect of the study is open to attack, at least to the individual who is fairly familiar with the strip operations by means of which phosphate rock is mined. To this individual the weakest spot in the study would appear to be the low degree of sensitivity inherent in the X_{42} variable, that variable which purports to measure the bone phosphate of lime content of the phosphate rock underlying each sample site. This low degree of sensitivity is not too worrisome for the citrus results, since phosphate mining and citrus growing are incompatible at the same location and since the contribution of phosphate ore to the value of a site is generally lower than the contribution of citrus production even if the citrus has suffered rather severe natural and/or pollution damages.[17] But this lack of sensitivity might be particularly troublesome for the correct interpretation of the pasture results, for even though grazing and phosphate ore mining are inimical, the contribution of the possibility of phosphate ore mining to the value of a site is often much greater than any contribution existing or future grazing could make.

In its present form, without additional information, one cannot be sure that the X_{42} variable really has any meaning. By taking into account only the quality of the phosphate ore underlying any given site, the X_{42} variable fails to consider what are generally acknowledged to be two additional major influences upon the value of a body of phosphate ore. These two additional major influences are the depth of the calcium phosphate matrix and the thickness of the overburden. Several sources in the literature assert that the value of a site to be devoted to the mining of phosphate ore varies directly with the thickness of the calcium phosphate matrix, that ore body whose extraction is the object of the mining. These same sources indicate, ceteris paribus, that the value of the site varies inversely with the thickness of the overburden overlying the calcium phosphate matrix.[18]

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[17] Compare Table XXVII of this chapter with Table XII of this chapter or Table VI of Chapter III.

The partial regression coefficient of major interest in this study is of course the X_{43} or frequency of pollutant fumigations variable. The partial regression coefficient of this variable assumes the expected signs for the citrus regressions in each set of years, but for the pasture regressions in the 1958-62 interval it takes on a magnitude that is at once statistically significant and positive. If either the thickness of the calcium phosphate matrix and/or the thickness of the overburden has approximately the same areal distribution as the explanatory variable for the frequency of pollutant fumigations, then the pollution variable could be capturing a substantial portion of the value or lack of value implicit in the calcium phosphate matrix and the overburden. This might occur simply because logically any given partial regression coefficient reflects not only the influence of the factor or factors which it ostensibly represents but also the influences of any other factors not included in the regression equation whose values happen to be associated with the value of the independent variable that is included. Thus if the calcium phosphate matrix' thickness was highly and positively correlated with the frequency of pollutant fumigations variable, one would expect the magnitude of the pollution variable's partial regression coefficient to be overstated when positive and understated when negative. Similarly, if the overburden's thickness was highly and negatively correlated with the frequency of pollutant fumigations variable, one would expect the magnitude of the pollution variable's coefficient to be understated when positive and overstated when negative.

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[18] I.M. LeBaron, "Phosphate Rock," in Vincent Sauchelli, ed., Chemistry and Technology of Fertilizers (New York: Reinhold Publishing Corp., 1960), p. 69; J.W. Dunlap and H.H. Jacobs, "Strip Mining Phosphate Rock with Large Walking Draglines," in J.F. McCloskey and F.M. Trefethen, eds., Operations Research for Management (Baltimore: Johns Hopkins Univ. Press , 1956) II, pp. 189-193; and J. B. Cathcart and L.J. McGreevy, Results of Geologic Exploration by Core-Drilling, 1953, Land Pebble Phosphate District, Florida, U.S. Geological Survey, Bull. 1946-K (Wash. D.C.: U.S. Govt. Printing Office, 1959) p. 240.

Insufficient information was available to allow the investigator to determine for all sample sites whether or not there was any fairly high simple association between the thickness of the calcium phosphate matrix, the thickness of the overburden, and the frequency of pollutant fumigations. However, of the 334 citrus and pasture observations having a value for the pollution variable greater than one, information did exist on the thickness of the calcium phosphate matrix and the thickness of the overburden for 220 of them.[19] For those 220 observations which simultaneously were subject to pollutant fumigations and which had some nonzero amount of phosphate ore underlying them, a matrix of simple correlation coefficients is presented in the following table, Table XXII. The matrix shows the simple correlation coefficients for various powers and for various powers of combinations of the weighted arithmetic mean depths of the calcium phosphate, X_{44}, and the overburden, X_{45}, and for the frequency with which the sample sites were subjected to pollutant fumigations. As can readily be seen, none of the matrix' elements, if judged by the usual standards, give adequate cause for the arousal of serious suspicion that the partial regression coefficients for the pollution variable, X_{43}, capture a substantial portion of the contribution to or detraction from site value due to the calcium phosphate and overburden depths. Thus even if the phosphate ore quality or X_{42} variable doesn't really measure anything,[20] we can be fairly sure that the regression coefficients for the frequency of pollutant fumigations variable, X_{43}, aren't made up of a confounding of the negative impact of pollution upon site value and the positive impact of unincluded phosphate ore value dimensions upon site value.

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[19] The number of acres in each observation underlain by calcium phosphate in depths less than or equal to zero, one, five, ten, twenty, and thirty feet, and the number of acres in each observation for which the calcium phosphate matrix was overlain by overburden in depths less than or equal to ten, twenty, thirty, forty, and fifty feet were calculated from "isopach" maps found in the following materials, all of which were written by James B. Cathcart: *Economic Geology of the Keysville Quadrangle, Florida*, U.S. Geological Survey, Bull, 1128 (Wash. D.C. U.S. Govt., Printing Office, 1963), 82 pp. + maps; *Economic Geology of the Plant City Quadrangle, Florida*, U.S. Geological Survey, Bull, 1142-D (Wash., D.C.: U.S. Govt. Printing Office, 1963), 56 pp. + maps; *Economic Geology of the Chicora Quadrangle, Florida*, U.S. Geological Survey, Bull, 1162-A (Wash., D.C.: U.S. Govt. Printing Office, 1963), 66 pp. + maps; *Economic Geology of the Lakeland Quadrangle, Florida*, U.S. Geological Survey, Bull. 1162-G (Wash., D.C.: U.S. Govt. Printing Office 1964) 128 pp. + maps; and *Economic Geology of the Fort Meade Quadrangle, Polk and Hardee Counties, Florida, op. cit.*, 97 pp. + maps. Where more than a single depth of calcium phoshpate and/or overburden was found on any given sample site a weighted arithmetic mean of these depths was calculated with the weights employed being the number of acres on the sample site of a particular depth.

Though we have good reason to think that the impact of unincluded phosphate ore value dimensions upon the partial regression coefficients for the frequency of pollutant fumigations variable is negligible, that measure of the contribution of phosphate ore to site value which we have employed still raises a problem which might make the partial regression coefficients for the X_{43} variable in the pasture and citrus models appear to be somewhat suspect. The problem raised by the use of bone

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[20] Given the rather low simple correlation coefficients between X_{42} and X_{44} and X_{45}, this is a distinct possibility.

TABLE XXII

MATRIX OF SIMPLE CORRELATION COEFFICIENTS FOR THE CALCIUM PHOSPHATE MATRIX, THE OVERBURDEN, AND THE FREQUENCY OF POLLUTANT FUMIGATIONS

	X_{43}	X_{44}	X_{45}	$\frac{X_{44}}{X_{45}}$	$(X_{44})^2$	$(X_{45})^2$	$\left(\frac{X_{44}}{X_{45}}\right)^2$
X_{42}	.1032	-.0481	-.2500	-.0614	-.0484	-.2327	-.0089
X_{43}		.0220	-.1246	.0053	.0564	-.1622	-.0690
XX_{44}			-.1494	.8721	.9822	-.1610	.8053
X_{45}				.8933	-.4450	.9490	-.1956

phosphate of lime content as a measure of the degree of presence of phosphate ore is that problem which is the constant nemesis of all econometric analysis: intercorrelation among the independent variables. The guise in which the problem appears in this study is the rather high simple correlation coefficients between the values assumed by the X_{42} and X_{43} variables in most of the cross-sections for both the pasture and the citrus models. A listing of these coefficients appears in Table XXIII.

All these simple correlation coefficients, particularly those for pasture, are well below the levels at which most analysts evidence serious concern with problems of multicollinearity.[21] Nevertheless, in order to dispel any doubts about the interpretations of the partial regression coefficients for the X_{42} and X_{43} variables, it seems worthwhile to ascertain whether any inflation of standard errors and therefore extreme uncertainty about the actual values of the partial regression coefficients for X_{42} and X_{43} is introduced by this intercorrelation.[22]

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[21] For all other simple correlation coefficients between the explanatory variables in the pasture cross-sections, the highest was a .4418 between X_1 and X_{24} in 1958-60. The highest for the explanatory variables in the citrus cross-sections was a -.5000 between log X_{27} and log X_{43} in 1957-58.

[22] At first glance, the rather high simple correlation coefficients between X_{42} and X_{43} in the table to follow, Table XXIII, and the quite low simple correlation coefficient for the same variables in Table XXII seems rather curious, if not entirely inconsistent. The reason for the disparity between the two tables is that the area in which data on the thickness of the overburden and the calcium phosphate matrix was unavailable corresponded almost exactly to the area in which the frequency of pollutant fumigations was greatest. Roughly, this encompasses the area from three miles east of the Polk-Hillsborough County line to four miles east of Bartow on the east-west axis, and four miles south of Lakeland to Fort Meade on the north-south axis. It is the area in which the highest quality phosphate ore deposits are found.

TABLE XXIII

SIMPLE CORRELATION COEFFICIENTS BETWEEN X_{42} AND X_{43} FOR ALL PASTURE AND CITRUS CROSS-SECTIONS

Pasture		Citrus	
Cross-Section	$r_{42.43}$	Cross-Section	$r_{\log_{42}.\log_{43}}$
1947-49	.5488	1947-50	.6466
1950-51	.4611	1951-53	.7867
1952-54	.4985	1954-46	.7081
1955-57	.4147	1957-58	.7200
1958-60	.4589	1959-60	.8226
1961-62	.5698	1961-62	.6907
1963-64	.4113	1963-64	.7592

In a multiple regression analysis, two or more independent variables are often intercorrelated. When this occurs the recommended procedure is to delete from the analysis that variable which appears to contribute the least to the explanation of the variations in the dependent variable since it is generally thought that the variable which actually contributes the most will assume some of the contribution of that variable which contributes the least, rather than vice versa. That is, not all the independent variables which economic theory would lead one to expect to have an influence on the dependent variable's variations can be included indiscriminately in a regression model no matter how many observations and therefore degrees of freedom are available, for certain pairs are likely to be associated in space and/or time. Unfortunately, it is generally agreed that there exist no satisfactory tests of the extent to which multicollinearity exists in a single regression equation.[23] Furthermore, in this study we have no a priori idea of the influence of the X_{43} variable relative to the X_{42} variable. Accordingly, equations IIC and IIIC for the citrus observations, and IIP and IIIP for the pasture observations have been formulated. These equations are as follows:

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[23] Cf. Arthur S. Goldberger, Econometric Theory (New York: John Wiley & Sons, Inc., 1964), pp. 192-194; J. Johnston, Econometric Methods (New York: McGraw-Hill Book Co., Inc., 1963), pp. 201-207; and E. Malinvaud, Statistical Methods of Econometrics (Amsterdam: North-Holland Publishing Company, 1966), pp. 187-192. However, for some recent work which points toward the possibility of "pragmatic diagnostics," see Donald E. Farrar and Robert R. Glaubner, "Multicollinearity in Regression Analysis: The Problem Revisted," Review of Economics and Statistics, 49 (Feb. 1967), pp. 92-107.

IIC. $\log Y_1 = \log a + b_4 \log X_4 + b_{27} \log X_{27} + b_{39} \log X_{39} + b_{42} \log X_{42}$
$+ b_{43} \log X_{43} + \log E + b_1 X_1.$

IIIC. $\log Y_1 + \log a + b_4 \log X_4 + b_{27} \log X_{27} + b_{39} \log X_{39} + b_{42} \log X_{42}$
$+ \log E + b_1 X_1.$

IIP. $Y_1 = a + b_1 X_1 + b_{24} X_{24} + b_{36} X_{36} + b_{43} X_{43} + E$

IIIP. $Y_1 = a + b_1 X_1 + b_{24} X_{24} + b_{36} X_{36} + b_{42} X_{42} + E$

In all four equations therefore, the difference between them and IC and IP is that X_{42} or X_{43} have either been added or deleted. If there is no substantial change from equation to equation in the partial regression coefficients for X_{42} and X_{43} and in their respective standard errors, then the existence of multicollinearity in the estimates is not substantiated. Table XXIV gives the partial regression coefficients of X_{42} and X_{43} and the associated standard errors for each cross-section of the three citrus equations. And Table XXV gives the partial regression coefficients of X_{42} and X_{43} and their associated standard errors for each cross-section of the three pasture equations. In order to ascertain the contribution of each variable to the coefficients of multiple determination and to the minimization of the standard errors of equations IC and IP, these same statistics are presented for other equations.

It is evident from Table XXIV that inclusion of the X_{42} variable in the citrus equations does have some injurious effect upon the X_{43} variable's partial regression coefficients and their associated standard errors. That is, the inclusion of the X_{42} variable in the estimating equation usually increases the standard error of the partial regression coefficient for the X_{43} variable, making the interpretation of that

TABLE XXIV

CITRUS: SELECTED PARAMETERS AND STATISTICS FOR EQUATIONS IC, IIC, AND IIIC

Parameters and Statistics Cross-Section and Equation		b_{43}	Standard Error of b_{43}	b_{42}	Standard Error of b_{42}	Coefficient of Multiple Determination	Standard Error of Equation
1947-50	IC	.009	.101			.729	.685
	IIC			-.102	.076	.745	.676
	IIIC	-.076	.080	-.098	.101	.745	.665
1951-53	IC	.043	.091			.829	.671
	IIC			-.042	.060	.831	.668
	IIIC	$.270^{c}$	.146	-.185	.146	.854	.638
1954-56	IC	-.069	.042			.824	.648
	IIC			$.094^{c}$	.050	.821	.644
	IIIC	-.051	.037	.132	.092	.808	.666
1957-58	IC	$-.086^{b}$	.039			.756	.779
	IIC			-.099	.073	.666	.769
	IIIC	$-.074^{c}$	.041	-.096	.075	.741	.802
1959-60	IC	$-.113^{a}$	.040			.877	.523
	IIC			.066	.044	.813	.523
	IIIC	$-.105^{b}$	.052	.091	.119	.854	.524
1961-62	IC	$-.174^{a}$	.057			.892	.526
	IIC			$-.147^{a}$	.043	.898	.527
	IIIC	$-.160^{b}$	.078	-.104	.078	.901	.526

TABLE XXIV

CITRUS: SELECTED PARAMETERS AND STATISTICS FOR EQUATIONS IC, IIC, AND IIIC (CONTINUED)

Parameters and Statistics Cross-Section and Equation		b_{43}	Standard Error of b_{43}	b_{42}	Standard Error of b_{42}	Coefficient of Multiple Determination	Standard Error of Equation
1963-64	IC	.002	.047			.810	.537
	IIC			.001	.038	.810	.537
	IIIC	.002	.068			.810	.542

[a] Denotes significance at the .01 level of the t- distribution.

[b] Denotes significance at the .05 level of the t- distribution.

[c] Denotes significance at the .10 level of the t- distribution.

TABLE XXV

PASTURE: SELECTED PARAMETERS AND STATISTICS FOR EQUATIONS IP, IIP, AND IIIP

Parameters and Statistics Cross-Section and Equation		b_{43}	Standard Error of b_{43}	b_{42}	Standard Error of b_{42}	Coefficient of Multiple Determination	Standard Error of Equation
1947-49	IP	.177	.302	.034	.179	.790	36.306
	IIP	.204	.262			.788	36.684
	IIIP			.084	.156	.790	36.427
1950-51	IP	.201	.273	.069	.167	.730	37.591
	IIP	.254	.239			.726	37.873
	IIIP			.127	.146	.729	37.717
1952-54	IP	1.370^a	.460	$.611^b$	.298	.765	54.819
	IIP	1.120^b	.420			.610	56.923
	IIIP			$.588^b$	.286	.598	59.856
1955-57	IP	-1.908^b	.774	$.726^a$	.209	.846	149.824
	IIP	-1.590	1.071			.740	165-688
	IIIP			$.712^a$	.218	.665	171.143
1958-60	IP	$.744^b$	.296	$.524^a$	.178	.885	129.859
	IIP	$.867^b$	.359			.755	131.260
	IIIP			$.542^b$	.226	.782	131.890

TABLE XXV

(CONTINUED)

Parameters and Statistics Cross-Section and Equation		b_{43}	Standard Error of b_{43}	b_{42}	Standard Error of b_{42}	Coefficient of Multiple Determination	Standard Error of Equation
1961-62	IP	3.957^a	.889	.888^b	.343	.829	212.859
	IIP	4.051^a	1.268			.720	214.333
	IIIP			.766^b	.365	.561	243.170
1963-64	IP	.038	1.927	-.762	1.501	.436	257.111
	IIP	-.280	1.802			.325	254.288
	IIIP			-.752	1.398	.336	253.303

[a] Denotes significance at the .01 level of the t- distribution.

[b] Denotes significance at the .05 level of the t- distribution.

[c] Denotes significance at the .10 level of the t- distribution.

coefficient more difficult. However, in no case--except in the 1947-50 cross-section where the partial regression coefficient for the X_{43} variable is statistically insignificant anyway--does the inclusion of the X_{42} variable change the sign of the X_{43} variable's partial regression coefficient. And even though the inclusion of the X_{42} variable does somewhat reduce the levels of statistical significance achieved by the X_{43} variable's partial regression coefficients, the reduction is never so serious as to confound and confuse completely the interpretation of these coefficients. To fret over achieving only a .10 or a .20 level of statistical significance rather than a .05 or .01 level is to perform in the spirit of a bookkeeper. The inclusion or the noninclusion of the X_{42} variable necessitates no substantial changes in the reasonable interpretation of the X_{43} variable, and that, for the purposes of this study, is all that really matters.

Failure to include the X_{42} variable in the pasture equations, however, does affect the extent of variation in the dependent variable, per acre sale price, that is explained by the independent variables. Failure to include either the X_{42} or the X_{43} variable generally results in substantial reductions in coefficients of multiple determination and increases the standard errors of the regression equation. More importantly though, for those cross-sections of Equation IP in which the partial regression coefficient of the X_{43} variable is statistically significant, the deletion of the X_{42} variable has no substantial impact upon either the X_{43} variable's sign or partial regression coefficient, nor does it have any impact to speak of upon that coefficient's standard error. Similarly, the deletion of the X_{43} variable from Equation IP has no meaningful impact upon the sign, magnitude, or statistical significance of the X_{42} variable. We thus stand on fairly firm ground when asserting that the possibilities of difficulties in interpretation caused by the fairly high simple correlation coefficients for X_{42} and X_{43} in the pasture cross-sections do not become actual when one compares the results of Equations IP, IIP, and IIIP. Thus, in summary, there exists no strong prima facie case against the use of those formulations IC and IP. They will therfore be used as the basis for the subsequent discussion.

V. INTERPRETATION OF EQUATIONS IC AND IP

Referring again to Tables XVIII and XIX and neglecting briefly that variable of major interest, X_{43}, it is apparent in most cross-sections that the signs of the partial regression coefficients for the other explanatory variables are in accord with logical expectations. In fact, the sole exceptions are the signs of the X_1 variable for the citrus results in 1947-50 and in 1963-64, and the signs of the X_{24} and X_{42} variables for the pasture results in 1961-62 and 1963-64 respectively. But none of the partial regression coefficients to which these inconsistent signs are attached are statistically significant at what are generally regarded as meaningful levels. The monotonically decreasing nature through time of the partial regression coefficient for the X_1 variable in the pasture results raises either some questions about the manner in which Polk County tax assessors have assessed improvements and/or the manner in which the investigator has entered either the values for or the form of the X_1 variable. However, since the partial regression coefficients for the X_1 variable closely approximate one in the years of greatest interest, i.e., the years in which fluoride emissions were at their historical maximums, the investigator has not bothered to attempt to find the reason(s) for this temporally decreasing sequence.[24] And even though one might profitably discuss at some length the implications in the various cross-sections of the partial regression coefficients for freeze damages to citrus, citrus age, urban proximity, site size, and the other explanatory variables, these matters are not of direct interest here.

Turning now to that variable which is of major interest, the X_{43} variable purporting to measure the extent to which a site has been subject to pollutant fumigations, we see that in the citrus cross-sections the variable's partial regression coefficients were positive but statistically nonsignificant until the 1954-55 cross-section. After 1954 and through 1962 the coefficients steadily increase in absolute magnitude, assume negative signs and are statistically significant. Given the multiplicative form of Equation IC and since the equation's dependent variable is a value rather than a quantity variable, the partial regression coefficient of the X_{43} variable in each of the citrus cross-sections represents a flexibility coefficient showing the percentage change in per acre site value relative to the percentage change in the frequency with which the site was subjected to pollutant fumigations. In short, the partial regression coefficient for the X_{43} variable is a number independent of any unit of measure showing the responsiveness of site value to changes in frequency of pollutant fumigations. The ratio of percentage changes in terms of which this flexibility coefficient is expressed is simply the absolute change in per acre site value relative to the absolute change in pollutant fumigations multiplied by the relative change in pollutant fumigations relative to the relative change in per acre site value. Thus we can, given continuous functional relations and constantcy in the other explanatory variables, determine the absolute change in the per acre site value due to a one unit increase in the frequency of pollutant fumigations. That is, we can estimate marginal damage costs to the Polk County citrus industry from the flexibility coefficient. In notational form:

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[24] Given the rapid increase since World War II in demand for both permanent and transient housing in Polk County, one might have some success in searching for an explanation of this phenomenon in terms of a discrepancy between the actual and the desired housing stock and a failure of assessments to adjust to the excess of current over equilibrium rents which this discrepancy might imply. The gradual approach through time to a partial regression coefficient of one for the X_1 variable would thus mean that assessments are now taking the discrepancy into account and/or that rents are now approaching equilibrium levels.

$$b_{43} = \left(\frac{X_{43}}{Y_1}\right)\left(\frac{\partial Y_1}{\partial X_{43}}\right) \qquad \text{or}$$

$$\frac{\partial Y_1}{\partial X_{43}} = b_{43}\left(\frac{Y_1}{X_{43}}\right)$$

The latter expression simply states that marginal damages to citrus from air pollution are equal to the flexibility coefficient times the per acre selling price per unit of pollutant fumigations.

Employing the above procedure for a ten-year old grove worth $1,000 that has already been subject to two months of pollutant fumigations,[25] an additional month of pollutant fumigations caused on the average in the 1961-62 cross-section a reduction of $87.00 in the grove's capitalized per acre value.

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[25] The reader will note that no account is taken here of whether or not the two months were consecutive: it is assumed that the value taken on by b_{43} is independent of the distribution of pollutant fumigations across the time interval considered by the cross-section.

$$\frac{\partial Y_1}{\partial X_{43}} = \frac{\$1,000}{2}(-.0174)10 = 500(-.0174)10 = -87.00$$

But if this same grove in this same cross-section had already been subject to ten months of pollutant fumigations, an additional month would result in a reduction of the grove's capitalized value of only $17.40.

$$\frac{\partial Y_1}{\partial X_{43}} = \frac{\$1,000}{2}(-.0174)10 = 100(-.0174)10 = -\$17.40$$

Summing these marginal damages over the arithmetic mean number of months sites in any one cross-section were subject to pollutant fumigations will give an approximation of the total economic damages suffered by a typical citrus site during the years included in the cross-section.

The smooth manner in which the partial regression coefficients for the citrus model increase in negative magnitude for successive cross-sections in the 1954-62 interval is in close accord with what is generally acknowledged by those on all sides of the Polk County air pollution problem to be the temporal pattern of atmospheric fluoride emissions from the phosphate plants. Though the writer has been unable to find records of total Polk County fluoride emissions before 1959,[26] nearly everyone agrees that these emissions reached their historical maximum of 39,000 pounds a day in 1958 or 1959. Since the rated engineering production capacity of P_2O_5 or equivalent almost tripled from 1954 through 1959 and since the amount of Florida land pebble phosphate rock mined increased by 2.5 times,[27] this general view seems to make some sense. In fact, comparison of the temporal pattern of the partial regression coefficients of the X_{43} variable for the citrus cross-sections with the temporal pattern of increases in Polk County's P_2O_5 or equivalent production capacity and associated fluoride emissions makes it appear that there was approximately a two year lag from 1952 or 1953 through 1962 in the response of citrus land values to changes in the volume of fluoride emissions. The first cross-section in which any inverse relation between the X_{43} variable and per acre sale price becomes apparent in the citrus model is in the 1954-56 cross-section. According to testimony presented before the Muskie Subcommittee[28] and according to at least one Florida State Board of Health publication,[29] supposed citrus damages from air pollution first began to receive extensive public notice throughout Polk County in early 1952. Similarly, by 1962 daily fluoride emissions were only half their 1959 levels, with substantial likelihood of further reductions. Yet, as Partition #1 in Table XXI of this chapter shows, the actual and expected reductions did not have much impact until 1964. But, in spite of

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[26] One might acquire some idea of the temporal pattern of these emissions prior to 1959 by performing various manipulations upon the data for phosphate rock mined presented in Table VII of Chapter III. However, in order to do this one would have to know the amount of this rock actually processed in Polk County, the type of processing the rock was subjected to and the air pollution control efficiency of existing phosphate plants for each year in question. This is data that is unavailable.

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[27] See Tables IX and X in Chapter III.

[28] Special Subcommittee on Air and Water Pollution, Clean Air, Part 1, 1964, Committee on Public Works, U.S. Senate, 88th Congress, 2nd Sess. (Wash. D.C.: U.S. Govt. Printing Office, 1964), p. 783.

[29] J. J. Schueneman, et. al., A Report on Florida's Air Resources, (Jacksonville: Florida State Board of Health, 1961) p. 7.

TABLE XXVI

REPORTED DAILY FLUORIDE EMISSIONS IN POUNDS FROM POLK COUNTY[a] ROCK PHOSPHATE PROCESSING PLANTS

Year	Particulate[b] Fluorides	Gaseous[c] Fluorides	Total Fluorides
1959	NA	NA	39,000[d]
1960	20,708	12,807	33,515
1961	10,617	18,141	28,758
1962	4,278	14,109	18,387
1963	5,666	14,088	19,754
1964	3,501	9,952	13,453
1965	NA	NA	9,500[d]
1966	NA	NA	11,700[d]

[a] Includes the Smith-Douglass plant in Hillsborough County.

[b] Fluoride containing material/u (micron) in diameter.

[c] Fluoride containing material/u (micron) in diameter.

[d] Approximation.

NA - Not available.

Source: Polk-Hillsborough Air Pollution Control District, Annual Activities Reports (Winter Haven, Fla: Florida State Board of Health, relevant years). (Mineographed.)

whatever lags in the responses of citrus growers may have occurred, the fact still remains that all the necessary ingredients for damages to citrus by airborne fluorides were present. The evidence seems to indicate that buyers and sellers of lands already devoted to citrus production acted as if citrus yields were and were likely to continue to be damaged by airborne fluorides emanating from phosphate plants.

In contrast, however, to the well-behaved manner in which the partial regression coefficients of the X_{43} variable in the citrus cross-sections conform to the initial hypothesis, the pasture results exhibit some inconsistency. More important, they generally directly contradict the initial hypothesis of an inverse relation for those years in which fluoride emissions were greatest between the frequency of pollutant fumigations and per acre sale price. Only in the 1955-57 cross-section of Equation IP is the initial hypothesis confirmed. In every other cross-section the partial regression coefficient of the X_{43} variable takes on a positive magnitude which for the 1952-54, 1958-60, and 1961-62 cross-sections is statistically significant at the usual accepted levels. The investigator's first and immediate reaction to these results was one of dismay. Yet a bit of reviewing of the historical background of Polk County's pollution problem caused these superficially seeming contradictory or at least inconsistent results to assume a unity and order which on qualitative grounds (and in the writer's opinion) seems eminently reasonable and even correct. Taken singly, these qualitative points may mean little if anything, but taken together in some unspecified mix they lend very substantial support to the regression results which state that the presence of air pollution has increased rather than decreased the value of Polk County pasture lands.

At the same time these qualitative points bring into bolder relief some of the reasons for the inverse relation between air pollution and the value in terms of sale price of citrus lands.

Any receptor who feels he has been harmed by air pollution has four avenues of action open to him. First, he may, if he thinks it best, simply sit back and stoically accept his fate--gasping perhaps. Second, if what he defines as air pollution constitutes an actionable nuisance, he may attempt to bring legal action either to collect damages and/or to obtain an injunction. Third, singly or in cooperation with other receptors, he may bring political pressures to bear in the form of threatened and/or actual governmental regulation of those thought to be placing pollutant materials in to the atmosphere. And fourth, just as the second and third courses of action are forms of indirect bargaining, he may bargain directly with the emitter, in the sense of purchasing from the emitter his freedom from what he thinks to be pollution's detrimental effects. Some receptors in Polk County have selected the first alternative, none have been able to afford the fourth alternative singly and none have felt it worthwhile to employ this alternative cooperatively, but there exist substantial numbers who both singly and cooperatively have acquired considerable solace through the intelligent use of the second and third alternatives. The material form assumed by this solace is the collection from the phosphate companies of prices for recpetor sites sometimes well above the highest price which could be obtained if any buyer wanted a site with similar attributes outside the area subject to fairly frequent pollutant fumigations.

In the early 1950's before the existence of an air pollution problem became evident to nearly everyone, those individuals owning land within the land pebble phosphate field received substantial benefits from the increase in land values caused by the entrance of new phosphate plants into the fields, the increased demand for phosphate rock, and the desire of phosphate firms already in the field to restrict entry into the phosphate industry and maintain the industry's cartel-like qualities by controlling the source of supply of the raw material.[30] The result was a general increase in the value of pasture sites in the land pebble area since knowledge of the precise location of many of the better quality phosphate deposits was uncertain[31] and since the land purchases by the phosphate companies were thought to make unavailable for grazing purposes the best of Polk County's pasture lands.[32]

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[30] On this last point see Jesse W. Markham, The Fertilizer Industry (Nashville, Tenn.: The Vanderbilt University Press, 1958), pp. 183-206. My calculations indicate that at present rates of mining, those phosphate companies presently in the field own sufficient deposits to last them from eighty to 120 years. Apart from the opportunity costs of holding land for this length of time, the costs in property taxes alone make it evident the land is being held for reasons in addition to phosphate rock mining. Somewhat ironically, at least from the point of view of allocative efficiency, it is possible that the attempts of the State of Floirda to ameliorate the effects of air pollution by pressuring the phosphate companies to buy up those lands subject to pollutant fumigations may have served to reinforce the already rather imperfectly competitive nature of the phosphate fertilizer industry.

[31] Conversation with W. B. Cox, a retired phosphate plant manager of Bartow, Florida on May 25, 1966.

[32] Conversation with W. Arthur Bissett, a cattleman and citrus grower of Bartow, Florida, on Aug. 24, 1965, and with E. B. Crum, a large-animal veterinarian of Bartow, Fla., on May 27, 1966. However, since the early 1960's the phosphate companies have leased their lands to cattleman at rates as low as ten cents per acre per month! But the leasing contract explicitly states that the phosphate companies are not

Those sites traded in the market were those sites thought, correctly or incorrectly, to contain substantial phosphate rock deposits or sites which were strategically placed for blocking the profitable mining of deposits on adjacent properties.[33] There is no reason to doubt that many sites not containing mineable phosphate deposits and not in a strategic position were traded for speculative purposes, the speculation being that the phosphate companies would purchase the sites in the near future. In the interim, the sites could be used for the grazing of cattle. Since sites already in citrus and sites suitable for citrus production in the immediate future were at least as valuable in their present uses as in any use associated with phosphate mining, it appears that citrus land values were unaffected by the expanding phosphate industry. Things soon changed however for both the cattle and the citrus industries, and with the change the welcome accorded to the phosphate industry wore rather thin.

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to be held responsible for any fluorosis acquired by the cattle. Several cattlemen, the largest of which is Kibler, Inc., of Lakeland , Fla., have found it advantageous to allow their cattle to graze on these phosphate lands for periods up to six months, then moving them to a location where they will be relatively free from environmental fluorides. And the phosphate companies appear to have acquired some rather substantial property tax advantages by such leasing arrangements, for in 1957 a law (Florida Statutes 193.11(3)) was passed by the Florida legislature stating that "all lands being used for agricultural purposes shall be assessed as agricultural lands upon an acreage basis." Though the Polk County Tax Assessor's Office continued to tax the lands owned by the phosphate companies on the basis of their phosphate rather than their agricultural value, a 1963 Florida Supreme Court decision which upheld the 1957 law forced the Office to tax such lands on the basis of their current agricultural uses.

[33] The phosphate companies can face substantial problems of land consolidation since their strip mining operations are seldom economic unless a single cut is at least one-quarter mile long. Cf. I.M. LeBaron, op. cit., p. 70.

TABLE XXVII

SUMMARY OF MATERIAL FOUND IN POLK COUNTY RECORDS DEALING WITH LAND SALES TO PHOSPHATE COMPANIES[a]

Year	Number of Items	Number of Acres	Per Acre Arithmetic Mean Sale Price in Nonconstant Dollars
1945	1	509	$ 330.00
1948	2	320	268.75
1950	3	1,050	316.44
1951	1	50	250.00
1952	2	900	389.00
1953	2	370	512.46
1955	4	1,714	491.16
1957	2	188	540.00
1958	3	360	600.00
1959	2	205	978.50
1960	2	100	856.75
1961	4	480	1,087.70
1962	3	370	854.25
1963	3	280	1,087.50
1964	3	800	1,076.06

[a] This table should not be viewed as giving anything more than an extremely crude impression of the prices the phosphate companies have been paying for agricultural lands, in spite of the fact that all these items were pasture or wasteland and contained no substantial improvements at the time of sale. It is interesting to note, however crude it might be to attempt to draw any implications from the table, that the years (1958-60) in which land prices paid by the phosphate companies increased by one-third corresponds very nicely with the years in which the partial regression coefficient for the X_{43} variable in the pasture model becomes positive and statistically significant rather than negative and statistically significant.

Upon noting the enervation of the health of their citrus groves and their beef cattle and attributing the responsibility to atmospheric emissions of gaseous and particulate fluorides from the phosphate companies, the first reaction of many in the citrus and cattle industries was to bring damage suits under the private nuisance doctrine against the phosphate companies. This avenue of defense is still being used by many in Polk County who think they have been and/or are being damaged by atmospheric pollution; and through its use the receptors appear to have had some moderate degree of success in imposing pressures upon the phosphate companies. Among the more notable successes of those who employed this tactic was a $208,124.38 court judgment against the Smith-Douglass Company for air pollution damages to the citrus and cattle of farmers living within a mile of the company's triple-superphosphate and phosphoric acid manufacturing facility.[34] Generally though, relatively few of the legal actions threatened by receptors have actually come to court,[35] for the mere threat of legal action has often been sufficient to get the phosphate companies to pay some rather outlandish prices for the receptor's land. One wealthy citrus grove owner purchased for $100,000 a grove relatively close to a phosphate company in 1960. The same grove was sold for $600,000 to the phosphate company in 1965. This same grove owner is still involved in litigation concerning another of his groves with Armour and Company. Armour tried desperately to keep this individual out of court by giving him a choice between $2 million for the grove while still allowing him to operate and collect the returns from it until the time to mine the area arrived, purchasing him another grove of similar quality for $2 million, giving him $2 million in cash, or $2 million in Armour's common stock. Though the fact that Armour was willing to give the grove owner the $2 million for the existing grove in 1964 while still allowing him to operate it and collect its net earnings implies that the grove wasn't bearing well and wasn't very likely to bear well in the future, the additional fact that Armour was willing to pay $7,407.41 an acre for 270 acres of citrus grove strongly suggests that considerations other than citrus and phosphate were involved in the propcsed deal. On similar lines, though the investigator has been unable to find a recording of the transfer, one story known to nearly all who have been close to the County's air pollution problems tells of the individual who purchased land in the middle of that area subject to pollutant fumigations, planted young citrus trees, waited for four years until they started producing, and thenthreatened to sue a nearby phosphate company for damages. In order to help the damage process along he even irrigated his trees with water from a stream flowing from a phosphate company constructed pond into which the phosphate company dumped its wastes, including the fluorides collected by its air pollution control equipment. The phosphate company rather than go to ccurt is said to have paid $13,000 an acre in 1963 for the site. In the same year another phosphate company paid $6,100,000 for 43 acres of land of which 35 acres was in pasture and which did not contain any improvements. This is equivalent to $14,186.05 an acre. The same company five months earlier had paid another individual $6,352.94 an acre for seventeen acres of land adjacent to the aforementioned site.[36]

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[34] Letter dated December 15, 1966, from John F. Turbiville of the Tampa, Florida law firm of McClain, Turbiville & Davis.

[35] Conversation with J. Hal Connor of the law firm of Summerlin and Connor, Winter Haven, Florida on November 28, 1966.

In general, at least until recently, the phosphate companies have been far less reluctant to go to court with the citrus growers than with the cattlemen. That is, the companies have much more readily settled out of court with the cattlemen than with the citrus growers.[37] The reason for this appears to be that it is generally much easier for a plaintiff to satisfy the court that airborne fluorides are a "proximate cause" of damages to his cattle than it is to prove that the fluorides are a "proximate cause" of damages to citrus. This appears to be due to the impression of the courts that knowledge about cattle fluorosis is much more specific and precise while that for fluoride damage to citrus is mostly a matter of conjecture. In fact, a perusal of some of the suits involving citrus damages makes it obvious that the phosphate companies have had considerable success in basing their defenses upon the multitude of other factors such as freezes, frosts, poor fertilization, and inadequate irrigation which can severely damage citrus trees.[38] The strategy followed by the phosphate companies appears to have been to allow suits to get into court whenever the company had an excellent chance of successfully defending itself, but of paying the receptor practically any amount to keep the case out of court whenever a successful defense was in some doubt. Allowing the case to go to court whenever a successful defense is unlikely encourages similar suits. In other words, a phosphate company failure to win a court decision encourages every receptor in the area to try his luck. It furthermore gives some legal backing and grounding in the common law to attempts of the state authorities to place increased pressure upon the phosphate companies. The desire to stay out of court appears to have cost the Polk County phosphate companies some very considerable sums. It is likely, though the exact magnitude cannot be known, that this desire and the companies' willingness to pay for its fulfillment has contributed to the positive relation between per acre sale price and frequency of pollutant fumigations in the 1958-62 pasture cross-sections. In addition, it is possible, though not necessarily highly probable that this wish to avoid conflict in a court setting may have reduced the magnitude of the inverse relation between per acre sale price and frequency of pollutant fumigations in the 1954-62 citrus cross-sections.

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[36] These transactions are recorded respectively in Polk County Official Record 745, p. 103, and Polk County Official Record 752 p.243.

[37] Conversation with J. Hal Connor of the law firm of Summerlin and Connor, Winter Haven, Fla., on Nov. 28, 1966. Schuenemann, et. al., op. cit., p. 26, also report that nearly all the cases which have actually come to trial since 1958 have involved a loss of citrus crops. Only a very small number of these cases on which a court decision was made were lost by the phosphate companies.

[38] There is now likely to be a radical change, for a Federal Court has recently ruled that Florida law states when a party causes damage in uncertain amounts, all doubts must be resolved against this party. That is, if a phosphate company causes any part of a citrus grower's or a cattleman's loss, the phosphate company is responsible for the entire loss and must compensate the citrus grower and/or the cattleman accordingly. Cf. Roe v. Armour, 370 F 2nd 829 (1967). Though the receptor must still show by the preponderance of evidence that the emitter caused

In spite of whatever successes the threat and/or actual use of court actions may have brought for receptors, their major bargaining

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some damage, the emitter when he asserts that the harm was done by " an act of God" must prove by the preponderance of the evidence that he, the emitter, did not cause any of the harm. The shoe appears to have been removed from the receptor's foot and placed on the emitter's foot.

strengths appear to have been based on political devices.[39] One of the major uses of the courts has in fact appeared to be as a means of dramatizing to the public the plight, actual or supposed, of the receptors. Presumedly an aroused public will place more pressures upon the administrative bodies established by the State to regulate air pollution in Polk County. One highly placed state official has remarked to the writer that the State has given more attention to Polk County's air pollution problem than to any other pollution problem in Florida solely because that area is the greatest source of complaints.

By 1955 the number and volume of complaints had become so great that the Florida State Board of Health was given authority by the legislature to promulgate air pollution rules and regulations. Two years later, in 1957, the legislature adopted the Florida Air Pollution Control Law, providing for the establishment of a Florida Air Pollution Control Commission having the authority to create air pollution control districts in which it could legislate control regulations.[40] From its inception, at least six members of the ten member Commission have had some direct everyday concern and connection with the Polk County air pollution problem. On March 21, 1958, one of the Polk County commissioners who happened to be a cattleman and citrus grower proposed the creation of the Polk-Hillsborough Air Pollution Control District, still the only air pollution control district created in Florida as of early 1967. Though the Control District is supposed to serve as the enforcement arm of the Commission, most people directly concerned with the air pollution problem, including those who work for the District, consider the District to be a part of the State Board of Health. More important, a large majority of people one talks to consider the Board of Health and therefore the District to view the dilemma of the phosphate companies with some sympathy, while these same people state that the Commission tends to view the cause of the receptors with more compassion. Recently this supposed difference in relative ardors has led some of those most closely involved in the attempt to ameliorate Polk County's air pollution problem to call for creation of an entirely new control agency entirely independent of or entirely dependent on the State Board of Health.[41] Since all receptor complaints must pass through the State Board of Health before a hearing on them can be authorized by the Commission and since all decisions taken by the

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[39] This is not to say that the legal means and devices are being laid aside. The most recent receptor maneuver of interest is a threat by a group calling itself the Citizen's Committee for (!) Air Pollution which proposes to seek injunctive relief against the phosphate companies under the public nuisance doctrine. That is, the receptors would bring a criminal rather than a civil suit against the phosphate companies based on the argument that these companies are annoying and/or injuring the health of the community. If the suit is actually brought and is successful, the phosphate companies would be ordered to cease all atmospheric emissions or stop their operations altogether. Even if this suit is unsuccessful, there is apparently nothing to prevent the phosphate companies from being harassed by an unending chain of these suits. This is because under the Florida law any private citizen may bring suit to enjoin a public nuisance. Cf. Fla. Comp. Gen. Laws 1927, Sec. 5029; Fla. Rev. Gen. Stat. 1920, Sec. 3223; and Fla. Laws 1917, c. 7367 Sec. 2. The laws state, in effect, that the private individual acts and can act in the name of the State of Florida and that no special damage need even be shown to him ! I am indebted to Paul G. Neimann for this point.

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[40] Fla. Stat. 403.03.

[41] See the letter dated Sept. 12, 1966, of E. R. Hendrickson, Chairman of the Administrative and Budget Committee of the Florida Air Pollution Control Commission, to George Westbrook, Chairman of the Florida Air Pollution Control Commission, reprinted in Florida Air Pollution Control Commission: Minutes, Sept. 16, 1966 (Jacksonville: Fla. State Board of Health, 1966), 4 pp. (Mimeographed.)

Commission must be enforced by District personnel who officially work for the State Board of Health, some degree of confusion, misunderstanding, and conflict is to be expected.[42]

Whatever the disagreements among those charged with the responsibility of ameliorating Polk County's air pollution problem, an attempt or rather a series of attempts have nevertheless been made to ameliorate it. Those means by which the Commission and the District were to enforce whatever rules and regulations were promulgated for the control of atmospheric emissions from the phosphate plants were "conference, conciliation, and persuasion."[43] When "conference, conciliation, and persuasion" failed the District could go to court under the public nuisance laws requiring that it show a danger to the health of the community. Only one case (against Armour and Co.) was ever taken to court and then the court failed to find for the District. Thus until 1964 about the only enforcement measures the Commission employed were the aforementioned synonyms for cajoling. That indicator adopted by the Commission for determining whether or not any cajoling was required was a level of fluorides in pasture grasses exceeding forty parts per million by weight. Since this pasture grass fluoride level was often exceeded in many locations in Polk County's southwestern quarter, the need for cajoling often arose. However, the Commission's accomplishments did not rest solely upon its eloquence, for always implicit in its attempts at persuasion was its ability to promulgate if it wished new rules with penalties attached having the standing of law.

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[42] Though many would disagree, this writer sees nothing inherently wrong with such conflict. In order to discredit the present system solely on the basis that there exists conflict within it, one would have to show that order is desirable solely for its own sake.

[43] Fla. Stat. 403.09.

The use of the forty parts per million pasture grass standard as an indicator of pollution did create problems for the District however. Though receptors constantly pointed out that the standard was being exceeded at many locations and even though levels in excess of the standard were the joint responsibility of all emitters, the Commission had no set of criteria by which it could assign degrees of responsibility to the various companies. The director of the District stated the problems this lack of criteria created for him in the following manner.

> "The old 40 parts per million regulation was not enforceable. We have spent too much time and money just developing knowledge that a violation of this regulation existed. It has been impossible to determine who or how many of the plants were in violation. When we find a violation, then we must prove who caused that. This is very difficult; which or how many of the companies caused that fluorine to be put in that grass. All we can do is present to the Commission and to the public that this grass is over 40 ppm. but we cannot prove who did it. Due to this, we have been badgered for the past four years something terrible."[44]

The approach taken to mitigate the enforcement difficulties caused by the lack of specific criteria for the assignment of responsibility for violations of the standard was one which had been discussed by Commission members and enforcement personnel for several years. One obtains the impression--and it is no more than an impression--in talking to members of the Commission and the District that the seriousness with which the alternative approach was considered at any one time was in direct proportion to the difference between the pressures receptors were able to apply and the pressures emitters were able to apply.[45] In any case, after a year or two of what appears to be rather discreet discussion in the State Board of Health and the Commission, the Commission in 1965 adopted a permit system limiting allowable fluoride emissions of existing plants to six-tenths of a pound of fluoride emissions each day per ton of each plant's highest recorded daily production of P_2O_5 or equivalent. For new plants, allowable fluoride emissions were established at four-tenths of a pound of fluoride emissions each day per ton of the plant's rated P_2O_5 or equivalent daily production capacity.[46] These ratios were selected because District calculations indicated that with existing and immediately planned P_2O_5 production capacity the total maximum daily fluoride emission level throughout Polk County of two tons a day which would follow from the application of the ratios would result in at least eighty per cent of the pollutant fumigations causing twenty-eight day pasture grass fluoride accumulations in excess of forty parts per million by weight to be limited to phosphate company owned lands and to lands owned by known phosphate land speculators.[47] Presumedly, therefore, the standards or ratios would have been established to allow a greater volume of emissions if more of the sites which would have been subject to pollutant fumigations at the higher ratios were owned by the phosphate companies.

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[44] Statement of K.K. Huffstutler, Director, Polk-Hillsborough Air Pollution Control District before the Florida Air Pollution Control Commission, Florida Air Pollution Control Commission: Minutes, April 16, 1964, (Jacksonville: Fla. State Board of Health, 1964), p. 7 (Mimeographed.)

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[45] For example, Paul Huff, a Commission member and a citrus grower residing in Bartow, Fla., stated in a conversation on May 24, 1966, that "Commissioners had discussed a permit system several times before (1964) but the subject was always dropped. Sometimes we discussed it very seriously."

[46] Rules of the Florida Air Pollution Control Commission. Chap. 28-3.03.

[47] Transcript of testimony of K. K. Huffstutler, Director, Polk-Hillsborough Air Pollution Control District, before the Florida Air Pollution Control Commission, May 29, 1964. (Unpublished.)

As Figure 11 shows, the land owned in 1964 by the phosphate companies and/or being held solely for phosphate purposes accounts for 234,000 acres of 63.2 per cent of the 370,000 acres within the isofluor defining that recorded twenty-eight day period, January, 1963, when the area experiencing excessive pasture grass accumulations of fluorides reached its historical maximum. And of the 136,000 acres not owned by phosphate companies, at least 40,000 acres are in urban or built-up areas, leaving approximately 96,000 acres within the largest recorded isofluor which are probably devoted to agricultural uses.[48] Since very few, if any, complaints about fluoride damages to citrus have come from the area outside this isofluor, it seems reasonable to conclude that all significant damages to Polk County agriculture from fluoride air pollution have taken place within this isolfuor. Though the writer does not possess information on yearly land purchases by the phosphate companies, in 1939 they owned 165,000 acres in Polk County.[49] Since mining activity did not accelerate until the early 1950's, it

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[48] This is perhaps a good place to take note of the fact that there has been no substantive evidence of fluorine damages to human health outside the phosphate plants. Florida Air Pollution Control Commission, "The Health Effects of Air Pollution in Polk County," Florida Air Pollution Control Commission: Minutes, Sept. 16, 1966 (Jacksonville: Florida State Board of Health, 1966) p. 6 (Mimeographed.) However, fluorine levels inside the phosphate plants have been known to reach levels supposedly harmful to human health. Cf. Division of Special Health Services, Industrial Hygiene Survey of the Phosphate Industry in Polk County, Florida (Wash. D.C.: U. S. Public Health Service, April, 1958) p. 17. (Mimeographed.) Nevertheless, whether inside or outside the phosphate plants, there is no danger of catching the hoof and mouth disease that one lady still crusading for "clean air" in Polk County is reputed to have accused the phosphate companies of giving her.

[49] Mansfield, op. cit., p. 8.

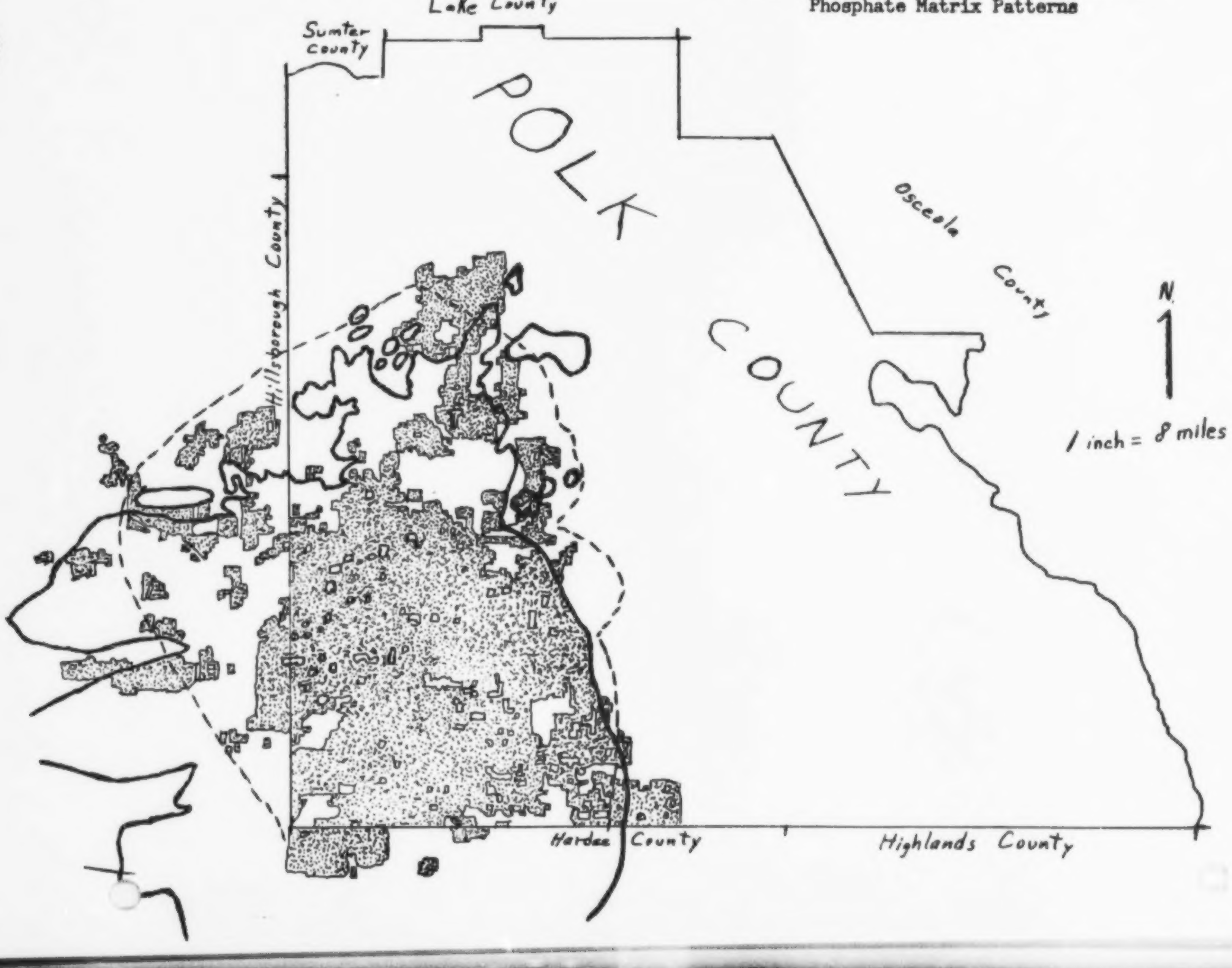

Figure 11

Land Ownership, Pollutant Fumigation and Phosphate Matrix Patterns

Lake County
Sumter County
POLK COUNTY
Hillsborough County
Osceola County
N.
1 inch = 8 miles
Hardee County
Highlands County

Key to Figure 11

A) The darkened area indicates the holdings of the phosphate companies and phosphate land speculators as of the end of 1965.

B) The heavy dark solid line is the "economic" zone of the calcium phosphate matrix according to Cathcart.

C) The light dashed line indicates the outermost recorded limit (Jan., 1963) of the forty parts per million by weight twenty-eight day fluoride accumulation in pasture grasses.

seems reasonable to suppose nearly all the 65,000 acres acquired by the companies between 1939 and 1964 were acquired from 1952 o4 1953 through 1964. Table XXVIII presents such information on Polk County phosphate ownerships as the writer does possess. This information does not contradict the regression results.

The pressures that receptors, particularly cattlemen, have been able through the Commission and the threat to use the courts to place upon the phosphate companies are not the only bases one can employ for justification of the pasture and citrus results. Cattlemen especially and even some citrus growers have been extremely reluctant to provide any information to the District about yields.[50] The forty parts per million standard for pasture grasses has been in effect since 1960, but, though a standard for accumulations of fluorides in citrus leaves has been discussed since nearly the birth of the Commission, no such standard has been adopted.[51] The phosphate companies have been accused by at least one man who has experimented with the effects of airborne fluorides upon citrus of using their influence with the Federal government to prevent him from obtaining a grant from the U.S. Public Health Service to carry on further experimentation. This assertion has been

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[50] Conversation with K. K. Huffstutler on November 30, 1966. The writer's experiences unfortunately confirm Mr. Huffstutler's statement.

[51] The most recent proposed citrus leaf standard is, "the presence of 20 ppm of fluorine in citrus foliage that can be identified as current spring flush foliage, or 100 ppm in the old leaves on the tree, shall be considered to be evidence of fluorine contamination of the atmosphere from some outside source; and that the presence of 60 ppm of fluorine in current spring flush foliage sampled prior to October first of any year shall be considered to be evidence of air pollution." Cf. Paul B. Huff, "Action of the Citrus Advisory Committee," Florida Air Pollution Control Commission: Minutes, April 15, 1966 (Jacksonville: Florida State Board of Health, 1966), p. 1.

TABLE XXVIII

PHOSPHATE COMPANY POLK COUNTY LAND OWNERSHIP IN ACRES

Year	Acres Owned	Net Purchases
1964	234,000	12,500
1962	221,500	7,500
1960	214,000	24,000
1957	190,000	

Source: Florida State Board of Health

made even though the phosphate companies contributed part of the pecuniary support for the original experimentation, the results of which gave some indication that the levels of fluorides present in Polk County's atmosphere could have harmed citrus yeilds.[52] Whether this gentleman be correct or incorrect in his assertion and in his experimental findings, the phosphate companies have now hired the Boyce Thompson Institute of Yonkers, N.Y., an organization part of whose concern is with plant pathology, to carry out research on the effects of fluorine upon citrus. The previous set of experiments lasted for three years, and the new ones under the auspices of the Boyce Thompson Institute are to last for an undetermined number of years. In any case, a reading of the Minutes of the Florida Air Pollution Control Commission makes it apparent that the usual response of the phosphate companies to a proposal for a citrus standard is that not enough is known. More significantly perhaps, the experimentation necessary to acquire the types of knowledge thought to be needed generally requires several years.

Other supports for our interpretation of the regression results exist. In 1962, Polk County citizens voted on a proposed zoning law which would have set aside that part of the county presently surrounded by phosphate plants as a dumping ground for pollutant materials. Even though the zoned area would have been substantially smaller than the area then being subjected to pollutant fumigations, the proposed law was handily defeated. Person after person in Polk County has stated to the writer that they would not purchase land for continuing agricultural purposes in the area known to be subject to pollutant fumigations but that they would readily buy land for purposes of sale to the phosphate companies. Mr. Paul B. Huff, a citrus grower and a member of the Florida Air Pollution Control Commission has stated that "the phosphate companies will tell a person to buy a piece of land and then buy it back at a great increase."[53] K. K. Huffstutler, the Control District's Director volunteered the information that there have been deals "between the cattle and citrus people and the phosphate industry, the deals have generally been in the form of land sales, and there has been a great disparity in prices paid."[54] Carl Lake, a Polk County real estate appraiser, asserts that land values within the area subject to pollutant fumigations have increased since the middle 1950's at a rate greater than that in "some" other areas of the County.[55] Dr. I. W. Wander, a botanist associated with the Florida Citrus Experiment Station in Lake Alfred, Florida, stated that he "would not plant or buy a grove in the polluted area except for purposes of sale to the phosphate companies."[56]

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[52] Cf. Florida Air Pollution Control Commission, "Possible Effect of Fluorides on Citrus," Proceedings of Hearings on Fluoride and Sulfur Oxide Emissions: June 2-3, 1966 (Jacksonville: Florida State Board of Health, 1966), p. 186.

Though one can go on at great length listing the qualitative evidence for support of the thesis that receptors have been fairly successful in imposing pressures upon the phosphate companies, such listings provide few insights into the reasons why the phosphate companies have been susceptible to these pressures. The reason becomes clear however when one realizes the two choices the Florida Air Pollution Control Commission has presented the phosphate companies since the Commission's inception: either buy up all those sites subject to excessive pollutant fumigations, i.e., all those sites having pasture grass fluoride concentrations greater than forty parts per million, or reduce emissions down to that level which is the technologically--not economically--feasible minimum level. Two officials of the State Board of Health, Mr. Vincent Patten and Mr. Kay K. Huffstutler, have stated explicitly to the writer that the objective of the State's policy has always been to present the phosphate companies with these two alternatives. When one adds to these two alternatives a third alternative of employing whatever political influence the phosphate companies may possess, it is evident that these companies have not been left without choices in the decision of what volume of fluorides to release into the atmosphere over any given interval of time. That is, at least until the initiation of the permit system in 1965, the phosphate companies had some choices as to the procedures they would follow; but, in contrast to the early 1950's when there was little if any own-cost attached to the release of fluorides into the atmosphere, whatever choice they made had an own-cost attached to it. That value dimension of the air--the waste disposal capacity--whose use by the phosphate companies had been free or at least nearly free now had a very substantial price tag. In accordance with the criteria of economic theory, the phosphate companies appear to have attempted to select whatever mix of the three alternatives seemed to be the minimum cost mix over any given interval of time. The attempt of these companies to minimize the costs associated with the alternatives they had before them caused most pasture lands in the area subject to excessive pollutant fumigations to become more valuable as dumping grounds for pollutant materials than as grazing land for cattle. But, perhaps due to the extreme uncertainty regarding the nature of fluoride damages to citrus, citrus sites, from the phosphate companies' viewpoint, remained more valuable in their present use rather than as a pollutant dumping ground.

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[53] Conversation of May 24, 1966.

[54] Conversation of Aug. 30, 1965.

[55] Conversation of May 23, 1966.

[56] Conversation of May 22, 1966.

VI. THE COSTS OF AIR POLLUTION CONTROL IN THE PHOSPHATE FERTILIZER INDUSTRY

The published information available about the costs of air pollution control in the phosphate industry is extremely sparse.[57] Furthermore, for most of that unpublished material obtained and used here, its sources cannot be disclosed. Nevertheless, even at its worse, this information does provide at least a hint of the upper bounds of air pollution control expenditure for phosphate fertilizer manufacturing plants of given production capacities and ages desiring to keep their fluoride emissions under some self-imposed and/or externally imposed upper limit.

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[57] The paucity of published materials is reflected in the following listing which after an extremely thorough search of the literature is all that could be found concerning the costs of controlling potential atmospheric emissions of fluorides: (a) C. C. Legal Jr., et. al., "Phosphoric Acid in the Clinker Process," Ind. Eng. Chem., 49, Pt. 1 (March, 1957), pp. 334-337; (b) Sidney Atkin, et. al., "Wet Process Phosphoric Acid; A Method of Recovering Fluorine as Sodium Silicofluoride," Ind. Eng. Chem., 53(Sept. 1961), pp. 705-707; (c) F. G. Heil et. al., "Pilot Plant Study of an Ammonium Fluoride Process for Recovery of Fluorine from Superphosphate," Agric. Food Chem., 9 (Nov. - Dec. 1961), pp. 457-459; (d) Konrad N. Semrau "Emission of Fluorides from Industrial Processes--A Review," Air Pollution Control Assoc., Journal, 7(Aug. 1957), pp. 92-108; (e) E. J. Fox, and W. L.Hill, "Factors Affecting Fluorine Volatilization during Acidulation of Phosphate Rock with Sulfuric and Phosphoric Acids," Agric. Food Chem.,7 (July 1959) pp. 478-483; (f) K. E. Lunde, "Performance of Equipment for Control of Fluoride Emissions," Ind. Eng. Chem., 50 (March 1958), pp 293-298; (g) J. A. Brink Jr. and C. C. Contant, "Experiments on an Industrial Venturi Scrubber," Ind. Eng. Chem., 50 (Aug. 1958) pp. 1157-1160; (h) E. J. Fox, et. al., "Fluorine Emission and Recovery," in U. S. Dept. of Agriculture and Tennessee Valley Authority, Superphosphate: Its History, Chemistry and Manufacture (Wash., D. C.: U. S. Govt. Printing Office, 1964) pp. 217-250; and (i) F. J.Harris, and B. Raistrick, "Gaseous Effluents from Fertilizer Granulation Plants," in Vincent Sauchelli, ed., op. cit., pp. 648-684.

Basically, any wet process phosphate fertilizer manufacturer has two means available by which he can reduce over any one interval of time his plant's volume of atmospheric fluoride emissions: retention of the fluorides in the fertilizer material and/or recovery of the fluorides after they have been liberated. The first of these alternatives involves changes in the processes of production themselves, while the second involves the installation and operation of equipment having no major function other than air pollution control and which might or might not necessitate changes in production processes. In general, production process changes and the use of specialized control equipment can be regarded as substitutes in air pollution control technology, for most process changes which contribute to air pollution control involve changes in the pollutant loading of the volume of air passing through the production process. The greater is the pollutant loading or the greater is the air volume in which a given pollutant loading is dispersed, the greater the degree of technical sophistication and money outlay in air pollution control equipment necessary to stay within a particular maximum emission limit. In actuality therefore, there are three not altogether independent substitution possibilities: the reduction of the air volumes to which the fertilizer material is exposed during the production process, the reduction of the quantities of fluorides evolved by varying such factors as reagent acid temperature, and the recovery of evolved fluorides by means of specialized air pollution control equipment. In short, the task the phosphate fertilizer manufacturer faces is to find that combination of process inputs, process air volumes, and air pollution control equipment which will minimize the costs of attaining and maintaining any given volume of fluoride emissions.

Initially, it was hoped that some reasonable approximation of the technical rates of substitution of these alternatives for each other could be established for a fairly representative concentrated phosphate fertilizer plant. However, the incomplete knowledge and information available about the responses of fluorides and phosphorus pentoxide to variations in important input parameters made the excerise ineffectual and unsuccessful.[58] Nevertheless, some heretofore unavailable and fairly detailed material on the costs of air pollution control in existing phosphate plants was obtained, tabulated, and analyzed. An explanation of this latter material follows. It provides substantial support for the thesis that the policies of the various public bodies directly or indirectly responsible for air pollution control in Polk County have enabled receptors--especially pasture owners--to capture a substantial portion of the value to the phosphate companies of the locale's air resources.

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[58] For an example of a quite successful attempt to do something of this sort in an environmental quality problem, see Paul H. Cootner and Georgy O. G. Löf, Water Demand for Steam Electric Generation, (Baltimore: The Johns Hopkins Press, 1965) 144 pp.

In Table XXIX is presented data on phosphate company capital and operating expenses for air pollution control in Polk County according to the Florida Phosphate Council. Since available indices distinguish chemical plant construction costs from chemical plant equipment costs[59] and since the extent to which Polk County phosphate company air pollution control outlays are divided between new plants and existing plants is unknown, no attempt is made to state this data in terms of constant dollars. In any case, this data does provide an idea of the magnitude of air pollution control money outlays by the Polk County phosphate companies,[60] though one must keep in mind that to the extent these air pollution control expenditures represent process changes which simultaneously increased production efficiency and/or to the extent the fluoride and phosphoric acid which is recaptured has a market value, these expenditures are overstated. Since it is to the advantage of the phosphate firm to make its air pollution control expenditures appear as large as possible--in order to impress all those who might impose pressure for emission reduction--it seems reasonable to presume the aforementioned data to be the gross and not the net costs of air pollution control, i.e., it is possible though by no means certain that the phosphate companies have not prorated these air pollution control e

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[59] Cf. Cecil H. Chilton, "Chemical Engineering Construction Index," Chemical Engineering, (April 25, 1966), p. 188.

[60] To an extent these magnitudes are understated, for some unknown but substantial portion of the 16 million dollars incurred in cumulative capital costs and the 4.5 million dollars in annual operating costs as of 1966 for water pollution control results from the attempts of the phosphate companies to prevent the pollutant materials collected by air pollution control equipment from polluting Polk County's watercourses.

TABLE XXIX

AIR POLLUTION CONTROL EXPENDITURES[a] IN NONCONSTANT DOLLARS BY POLK COUNTY PHOSPHATE COMPANIES

Year	Cumulative Capital Outlays	Annual Operating Expenses
1959	$ 6,737,221	$1,029,078
1960	7,987,081	1,057,678
1962	9,516,138	1,231,000
1963	11,650,411	1,259,314
1964	16,448,624	1,559,500
1965	18,907,527	1,873,350
1966	22,762,270	3,002,750

Source: Florida Phosphate Council, Lakeland, Fla.

[a] Production process changes and plant and equipment only.

expenditures between improvements in production efficency and improvements in air pollution control.[61]

Since any use of the material in Table XXIX must be so surrounded with qualifications and disclaimers as to render its usefulness quite doubtful, it seems best to consider the air pollution control costs borne by individual phosphate plants. Only then might one acquire some insight into the reasons why the phosphate companies have often found it more expedient to purchase receptor lands rather than to install air pollution control equipment and/or carry out changes in production processes. Accordingly, the following material is presented on the capital costs of air pollution control in the Polk County phosphate fertilizer industry. Included are changes in the production processes within an existing plant as well as the addition of specialized air pollution control equipment.

Of the four different plants included in this material on the capital costs of air pollution control in the phosphate industry, one is simply a phosphate rock drying and grinding plant while the other three are concentrated superphosphate plants.[62] In 1966, one of the concentrated superphosphate plants was about fifteen years old, another was slightly less than ten years old, and a third was only a year or two old. The phosphate rock drying and grinding plant was about five years old in 1966. No plant has ever been completely shut down for more than two months. All the triple-superphosphate plants are completely integrated operations producing phosphoric acid and triple-superphosphate, granulated and ungranulated. All the improvements in air pollution control which are referred to took place either in 1964 or 1965; thus all cost figures are in 1964 or 1965 dollars. One of the triple-superphosphate plants is not in the Florida phosphate field, but this in no way affects its cost relations for air pollution control. One of the triple-superphosphate plants daily consumes slightly over 1,000 short tons of dried and ground phosphate rock containing 3.2 per cent fluorine by weight, the second over 3,000 short tons daily of dried and ground phosphate rock containing 2.8 per cent fluorine by weight, and the third about 2,200 short tons daily of dried and ground phosphate rock containing 3.5 per cent fluorine by weight. Both production process changes and the addition of specialized air pollution control equipment were carried out in each triple-superphosphate plant.

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[61] Though the industry sells some of the fluorides it captures, these sales constitute only a small portion--less than ten per cent--of the total fluorides captured. As for the phosphorus pentoxide captured by the air pollution control equipment, the available engineering material balances indicate that potential emissions of this chemical compound are no more than one per cent of the compound in the end product.

[62] Though only capital costs are presented, it is not unreasonable to assume the air pollution control devices and process changes selected for each of the plants were truly minimum cost selections even when their operating costs are taken into account. The rule of thumb said to be employed by air pollution control engineers in the Polk County area is that the annual maintenance cost of specialized air pollution control equipment is six per cent of the total capital cost and that the time interval relevant for depreciation purposes is ten years.

In all cases, the raw information which was available was premised on the plant in question changing its daily emissions of fluorides from some higher figure to some lower figure. That is, the managers of the plant hired engineers considered expert in controlling atmospheric fluoride emissions from phosphate fertilizer manufacturing, telling them to find the minimum cost way of getting from the higher to the lower figure. The findings of the engineers, from which the material to be presented here is derived, are thus valid only for the costs of getting from X level of emissions to Y level of emissions per day $(X > Y)$ for the plant in question at the particular time in which the engineers made their study. For another plant, or for the same plant at the same age but where the desired reduction in emissions is greater or less, or for the same plant at a given point in time, the configurations of control costs might well have been different.

Keeping the remarks of the preceding paragraph in mind, the costs of air pollution control as they are presented here for various levels of collection efficiency were arrived at by taking the engineering studies for each plant and calculating the engineering cost estimate of reducing emissions from one level to another level at that particular point, step, or stage in the production process where the incremental capital cost of achieving a given increase in collection efficiency was at a minimum. This procedure assumes then that installing the control devices and/or changing the production processes all at once results in the installation of the same devices and in the same process changes at the same stages in the production process as when each device is installed and each process change is made only one after the other. In other words, it assumes that going from X to Y all at once results in the same mix of devices and process changes as does going there gradually. Furthermore, though each total capital cost function in Figure 12 is drawn as being continuous, each is actually simply a collection of point estimates. Nevertheless, there were at least ten point estimates on each curve--one curve had twenty-two--and each curve had at least two points in the immediate neighborhood of every inflection or where there was a sharp change in the curve's slope.[63]

Defining collection and/or retention efficiency as simply the ratio of the fluorides not emitted into the atmosphere to the fluorides present in all inputs, a glance at the total capital cost functions of Figure 12 makes it evident that once a fluoride collection or retention efficiency of ninety-five per cent has been achieved in a triple-superphosphate manufacturing facility, further increases in this

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[63] No econometric analysis was employed or attempted because three or four firms can hardly be said to represent a sample adequate in size to employ an econometric analysis. But even if sample size had been adequate for an econometric analysis, one must have serious doubts about the efficacy of the econometric approach where the essence of the problem is essentially of an engineering nature. The economist's production function assumes that the firm employs, given its budget constraint, the best available technology. Large amounts of information on the best available technology for achieving any given level of a given output are available in the engineering literature. Given knowledge of the market price of inputs, it seems much better to construct cost functions and productivity functions from the material in this literature rather than from a cross-section and/or time series of accounting data from plants having different managerial efficiencies, differences in the qualities of specialized factors of production, and differences in the ages and types of capital equipment which has not been fully depreciated. In addition to the inherent difficulties of explaining these differences between and among individual plants, one must also recognize that firm management often selects among several alternatives presented to them by engineers. If the process and/or scale selected by management is in some sense suboptimal, the error will ultimately be capitalized and therefore reflected in the accounting data. A serious bias is thus introduced into the analysis based on accounting data that cannot be shaken out unless one returns to the original engineering alternatives--an obvious impossibility in most cases. For explaining differences between and among firms in time and/or over time, the econometric approach is clearly preferable. But when trying to determine the minimum cost manner of achieving and maintaining a given objective, one is not interested in explaining such differences.

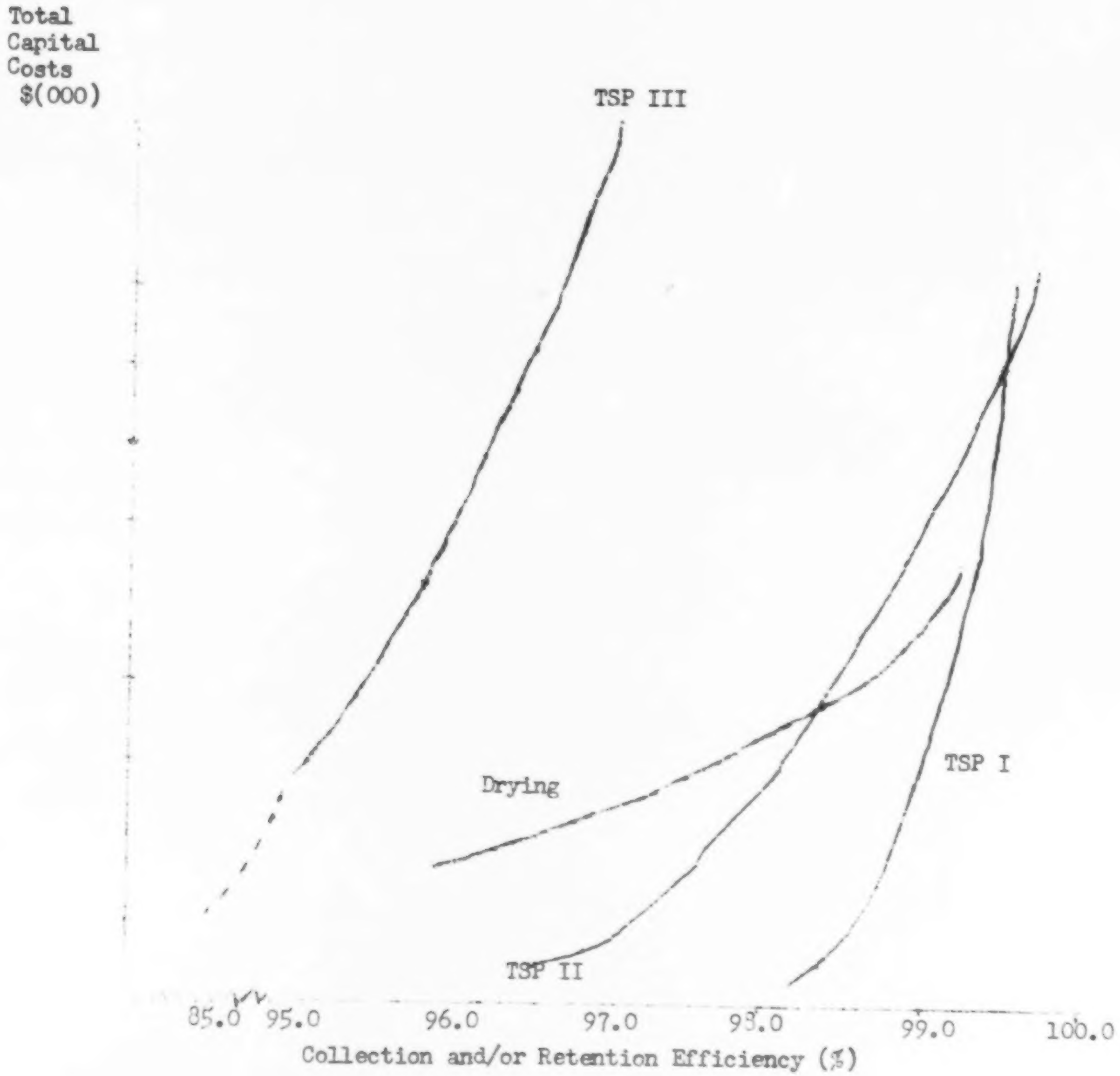

FIGURE 12

CAPITAL COSTS OF AIR POLLUTION CONTROL

Key to Figure 12

A) TSPI is the one or two year old triple-superphosphate plant which daily consumes over 3,000 short tons of 2.8 per cent fluorine content phosphate rock.

B) TSPII is the slightly less than ten year old triple-superphosphate plant which daily consumes over 1,000 short tons of 3.2 per cent fluorine content phosphate rock.

C) TSPIII is the fifteen year old triple-superphosphate plant which daily consumes about 2,200 short tons of 3.5 per cent fluorine content phosphate rock.

D) The curve labeled Drying indicates the total capital cost function for air pollution control in the five year old phosphate rock grinding and drying plant.

efficiency become extremely expensive. Similarly, though the total capital cost function for fluoride air pollution control in the phosphate rock drying and grinding plant does not reach the absolute magnitude of the control-costs for the triple-superphosphate plants, it too increases very rapidly once the ninety-nine per cent level of collection efficiency has been reached. For the triple-superphosphate plants, in fact, once something approximating the ninety-nine per cent level of fluoride collection and/or retention efficiency is approached, an outlay of at least $75,000 (TSPI) and perhaps as great as $200,000 (TSPIII) is required in order to achieve an increase of one-tenth of one per cent in collection and/or retention efficiency. In fact, given that the manner in which they have been obtained is correct, the total capital cost functions for the triple-superphosphate plants are definitely exponential, with the independent variable, collection and/or retention efficiency having an exponent between unity and two. In other words, once control and/or retention efficiency reaches the ninety-five per cent level, it becomes relatively unresponsive to increased air pollution control expenditures and the control efforts associated with these expenditures.

From Table VII in Chapter III, we know that the Florida land pebble phosphate rock used for the production of phosphoric acid and triple-superphosphate increased from 1.32 million long tons in 1953 to 5.50 million long tons in 1963. Since during this time interval nearly all phosphoric acid and triple-superphosphate production located east of the Mississippi River and in the Mississippi River Valley was located in the Polk-Hillsborough County area of Florida,[64] it is perhaps not unreasonable to assume that all this rock was processed in Polk County and its immediate environs. If we further assume Florida land pebble rock has an arithmetic mean fluorine content of 3.3 per cent by weight,[65] then the number of pounds of fluorine annually entering the Polk County phosphoric acid and triple-superphosphate manufacturing processes can be obtained by the following simple identity:

$$F = .033\ (2{,}240P),$$

where F is the annual number of pounds of fluorine and P is the annual number of long tons of phosphate rock processed for concentrated superphosphates. Though we do not have any information on fluoride emissions before 1959, we can convert the daily emission rates of Table XXVI in this chapter to annual totals simply by multiplying by 365. Annual collection and/or retention efficiency of fluorides for the Polk County phosphate industry is then given by:

$$\lambda = 1 - \frac{365E}{.033\ (2{,}240P)},$$

where λ is collection and/or retention efficiency, and E is the daily emission rate of fluoride for the year in question. The results of these calculations are given in Table XXX.

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[64] See K.D. Jacob, "History and Status of the Superphosphate Industry," U.S. Dept. of Agriculture and Tennessee Valley Authority, op. cit., p. 49. "Although exact figures are not available, it appears that in 1959, for example, around 85 per cent of the total production of available phosphoric oxide as concentrated superphosphate was made in Florida from locally mined rock. Florida supplied about 90 per cent of all the phosphate rock used in the United States production of concentrated superphosphate in 1959."

[65] W. L. Hill states that most Florida land pebble phosphate rock has a fluorine content by weight ranging between 3.3 per cent and 3.9 per cent. Cf. W.L. Hill, "Raw Meterials," Ibid., p. 99.

If anything, Table XXX underestimates the control and/or retention efficiencies achieved by the phosphate companies. The 3.3 per cent fluorine content basis on which the annual amounts of fluorine entering the phosphoric acid and triple-superphosphate manufacturing processes were calculated is at the lower pole of the range estimated by Hill. Similarly, some relatively small but unknown amount of the phosphate rock employed in these efficiency calculations was not processed in Polk County and its immediate environs. This too would tend to increase the efficiency calcualtions of Table XXX. Finally, because of such factors as breakdowns, repairs, strikes and periods of slack demand, it is unlikely that each and every plant in the field operates for 365 days each year. Therefore, if the Florida State Board of Health arithmetic mean daily emission figures for fluorides are correct, the major and really the only sources of error in the control and/or retention efficiency estimates of Table XXX are sources leading to increases rather than reductions in these estimates. That is, control and/or retention efficiency in the Polk County phosphate industry has probably been higher than the estimates of Table XXX. Table XXXI, which presents collection and/or retention efficiency figures for several of the Polk County triple-superphosphate plants in 1961-65 does not contradict the conclusions drawn from Table XXX.

Nevertheless, even with the probably low efficiency estimates of Table XXX, it is evident that by 1959 some of the sixteen phosphate plants[66] then in Polk County and environs must have already been

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[66] This includes phosphate rock drying and grinding plants, as well as phosphoric acid and triple-superphosphate plants.

TABLE XXX

ANNUAL COLLECTION AND/OR RETENTION EFFICIENCY OF FLUORIDES BY POLK COUNTY PHOSPHATE INDUSTRY

Year	F^a	$365\ E^a$	λ^b
1953	97.57		
1954	128.62		
1955	162.62		
1956	164.84		
1957	186.28		
1958	212.15		
1959	280.90	14.24	94.93
1960	300.12	12.23	95.92
1961	317.86	10.50	96.70
1962	345.95	6.71	98.06
1963	406.56	7.21	98.23

[a] Millions of pounds.

[b] Per cent.

TABLE XXXI

FLUORIDE COLLECTION AND/OR RETENTION EFFICIENCIES FOR VARIOUS POLK COUNTY TRIPLE-SUPERPHOSPHATE PLANTS

Plant	Year	λ
A	1961	72.06%
A	1962	81.15
A	1963	83.37
A	1964	87.38
B	1964	96.24
B	1965	96.44
C	1964	96.83
D	1964	98.29
E	1961	93.45
E	1964	97.38
F	1964	96.71
F	1965	99.71
G	1961	93.05
H	1965	99.41
I	1963	98.17

approaching that portion of their control cost functions where collection and/or retention efficiency is relatively unresponsive to control expenditures. Furthermore, if any plants were well below the level of ninety-five per cent collection and/or retention efficiency, then other plants must have been in those intervals of their control cost functions where an increase of one-tenth of one per cent in one plant's efficiency would in 1964-65 prices require a money outlay approximating a quarter-million dollars. At these costs, the willingness of the phosphate companies, once given no alternative, to substitute for emission abatement by purchasing receptor lands and by employing whatever political and legal measures are at their disposal becomes understandable. And to the extent receptors have recognized the costs of air pollution control for the phosphate companies, these receptors have been able to capture some portion of the value of the air's waste disposal dimension, where that value is defined as the cost of controlling atmospheric fluoride emissions. That is, once the Florida Air Pollution Control Commission and the Florida State Board of Health told the phosphate companies to button up and/or buy up receptor lands, the receptors--at least the more astute pasture owners--were able to capture a substantial portion of that value of the air's waste disposal dimension which had formerly accrued only to the phosphate companies. However, the actions of the Commission until 1964 did not in general assist owners of citrus groves because, with or without air pollution, the value of the citrus sites when devoted to citrus production remained more valuable than when used as a dumping ground for pollutants.

CHAPTER VI

SOME IMPLICATIONS OF THE LAND VALUE STUDY

The results of the previous chapter are no less than superficially surprising. Though, as one would expect, a negative relation was found between citrus land values and frequency of pollutant fumigations, for several years a positive relation was found between pasture land values and frequency of pollutant fumigations. It was argued that the latter relation can reasonably be attributed to that policy of the State of Florida which gave the Polk County phosphate companies a choice of either buttoning up their production processes and/or buying out those pasture sites subject to pollutant fumigations. The effect of this policy was to make these pasture sites appear more valuable to their owners as primarily dumping grounds for pollutant materials rather than as primarily grazing land for beef cattle. In short, the air pollution control policy selected by the Florida authorities provided those pasture owners both perceptive enough to recognize the State's policy and willing to participate in the market with an opportunity to capture a substantial portion of that captalized value of the air's waste disposal abilities which formerly had accrued only to the phosphate companies or to the relatively few cattlemen and citrus growers who could afford to threaten the phosphate companies with a protracted court fight.

The question as to whether or not the ultimate result of the above policy has served to minimize the sum of citrus and cattle air pollution damage costs and phosphate company air pollution control costs is a difficult one to answer. Determination of the extent at any one point in time or over any one interval of time to which such minimization has been achieved would require a rather precise knowledge of the areal distribution of receptor damage potentials and a fairly intimate knowledge of the attributes of the production processes and the inputs employed by each phosphate company. Given the poor quality (for purposes of economic analysis) of knowledge about the technical relationships underlying citrus and cattle damage functions and given the small size of the sample for phosphate plant control costs, a determination of this sort would bear a close family resemblance to conjecture.

Nevertheless, if one considers only the value of pasture land to the cattle industry when used solely for grazing purposes and the prices the phosphate companies have been paying for this land in order to reduce the chances of having to get emissions down to the minimum technologically feasible level, there can be little doubt that any attempt actually to reach this level would be highly uneconomic: there would be too few rather than too many emissions. What happens to the validity of this statement when one includes citrus is questionable because the expectations of existing and potential citrus grove owners about their economic environment, including the extent to which they will suffer from pollutant fumigations, determines the present market value of a citrus site. Since the extent of damages citrus grove owners expect to suffer appears to be strongly influenced by their expectations about the not altogether clear or visible policies to be followed by the various Florida air pollution control agencies, it is difficult to determine even the direction of the bias introduced by expected control policies into the partial regression coefficient for the pollution variable in the citrus equations.

Given, however, the positive sign often assumed by the partial regression coefficient for the pollution variable in the pasture equations, one can reasonably presume that the direction of the aforementioned bias introduced into the citrus equations was positive. That is, the various participants in the market for citrus groves generally felt that the policies of the various pollution control agencies would serve to reduce future pollutant fumigations, though not to the extent that all pollutant fumigations would be done away with. In summary then, the values assumed by the coefficients of the pollution variables in Chapter V reflect the expectations of citrus and pasture owners (and phosphate companies) about future pollutant fumigations only as seen through the screen of these owners' and companies' expectations about the future attitudes of the control agencies toward atmospheric fluoride emissions. If the owners' and companies' expectations about future control agency attitudes and powers had been different, the values assumed by the pollution coefficients would have been different, i.e., air pollution damages would have been different. In short, expectations about future control agency attitudes and powers had at least as substantial an impact upon economic damages as did existing pollutant fumigations.

Though no minimization of air pollution damage costs and control costs can take place without first deciding just what it is that constitutes optimal citrus grower, pasture owner, and phosphate company expectations about future control agency attitudes and powers, it is worth noting that expectations about the control policies to be employed by the Florida authorities were sufficient to establish and to make visible unexploited gains from trade. The control policy employed by the Florida authorities and the expectations derived from it opened up to both receptors and emitters the possibility of some compromise between complete surrender and complete intransigeance. To the extent the value of the gains in trade generated by existing and potential receptor and emitter expectations about the authorities' future control attitudes and powers outweighed the value of any losses in trade passed on to the customers of the phosphate companies, the citrus growers, and the cattlemen, an improvement in welfare was brought about. And if one abstracts from general equilibrium concerns so as to view the cattlemen, citrus growers, and the phosphate companies in isolation, it is clear that the policy brought about an improvement in welfare--though not necessarily an attainment of miximum welfare--because possibilities for additional gains from trade were provided with no other trading opportunities being destroyed.

Before the initiation of the control policy, the theoretical property rights the receptors had in the air space above their properties were actually nonexistent because these rights were nonenforceable or enforceable only at great expense--by going to court, for example. Similarly, the emitters, since they could acquire no benefits from having the receptor lands put to any use other than as dumping grounds for pollutant materials and/or as mining properties, had no incentive to consider the alternative valuable receptor uses for these lands. The property rights of the receptor in the air space above his land were valueless because they were quite unenforceable and the proprietary interest of the emitters in the receptor's land uses did not exist. But with the initiation of the control policy, the receptors' rights in the air space above their property did acquire value because it became possible for receptors to exercise substantial influence over the uses to which at least those rights associated with pasture sites would be put. Simultaneously, the uses to which receptor sites could and would be put became a matter of interest to emitters because the severity of controls imposed upon emitters could be expected to vary directly with the damage susceptibilities of receptor site uses. The newly acquired more enforceable property rights of the pasture site owners served to transfer a relatively large portion of the capitalized value of the air's waste disposal abilities from the phosphate companies to these owners. With the initiation of the control policy, the phosphate companies found it worthwhile to purchase pasture sites subject to pollutant fumigations only because the additional cost of most such purchases had become less than the additional cost of achieving greater control over the release of pollutant materials into the atmosphere. Except insofar as it reduced the level of emissions, the control policy was not of much assistance to citrus growers. But this perhaps can be attributed to the implicit recognition by the State authorities that a policy giving as an alternative the accelerated purchase of citrus sites would, because of the high cost of acquiring these sites, bring about substantial reductions in emission volumes. Nevertheless, regardless of whether the result was intended or unintended, the effect of the control policy upon most citrus growers was to reduce the frequency and the intensity of the pollutant fumigations to which they were subject.

Even though the control policy selected by the Florida authorities did not apparently make it worthwhile for most of the citrus growers and the phosphate companies to bargain directly with each other, it did make it worthwhile for the cattlemen and the phosphate companies to do so. The change in the proportion and the mix of enforceable property rights available to receptors relative to emitters produced potential gains from trade which had not before existed. The result was the internalization of most of the negative externalities which had been imposed upon cattlemen and a reduction in the negative externalities being imposed upon citrus growers. The two sides had previously exhausted all the gains of trade available within the set of rules and property rights which had been operative, but with the introduction of a new set of rules and property rights new gains from trade were opened up and the possibility of an impasse was at least ameliorated if not altogether avoided. The agenda over which it was worth the while of receptors and emitters to bargain had been widened, for the receptors could put pressure upon the emitters to either buy them out or cease releasing pollutants into the atmosphere. The control policy placed some strong cards in the hands of the receptors, whereas formerly these receptors held no cards at all other than that rather weak one involving the threat of a court suit.

The Polk County case is an example of the fact that although air pollution externalities are synonymous with a dissocation of social and private benefits and/or costs implying the possibility of a violation of the marginal conditions for a Paretian improvement in welfare, they are also services and disservices which can be exchanged and/or substituted for and will be provided that opportunities for trading and substitution are made available, i.e., providing that exchange and/or substitution is made worthwhile. The provision of opportunities which make exchange and/or substitution worthwhile in an air pollution problem necessitates revisions in the schedules of benefits and costs receptors and emitters will face when they take various courses of action. Thus the task confronting an air pollution control authority is the selection of that revision in receptor and emitter benefit and cost schedules which will serve to maximize the social surplus derived from the air resource. However, any such revision in benefit and cost schedules necessarily involves some changes in actual or operative, though not necessarily theoretical, property rights. And the revision in property rights means the courses of action selected by either emitters and/or receptors will differ from what they formerly were. Any proposal for a control policy must therefore give careful attention to the courses of action likely to be selected by emitters and receptors after the initial application of the policy as well as the courses of action selected by emitters and receptors prior to the policy's application. In short, the character of the gains from trade and substitution possibilities arising after the initial application of a control policy must not be neglected in any discussion of an air pollution control policy's economic efficacy.

I. PROPOSALS FOR THE CONTROL OF AIR POLLUTION

Those control policies resulting in revised emitter and receptor operative property rights which have garnered the greatest favor among those dealing with and writing about air pollution and similar problems of environmental quality are the imposition of effluent standards and the imposition of effluent charges. The stated intent of all such proposals, whether they be espousing the standard or the charge, is to impose the control measure upon the emitter, that party who is nearly always automatically assigned the full responsibility for the existence of the air pollution problem. In the engineer's or administrator's world, the choice between the standard and the charge seems to be a function of the individual's acquaintanceship with the elements of economics. The greater his acquaintance, the greater the likelihood he will favor the charge over the standard, even though the question of just what this charge should be and the criteria to be used for ascertaining the degree of effort to be employed in determining it is generally carefully sidestepped.[1] However, since an economically efficient emission or effluent charge at a point in time necessarily implies an economically efficient quantity of emissions or effluents--and vice versa--the basis for selection between the two--if one insists that such a selection must be made--must rest upon the degree to which each will tend to maintain maximization of the air resource's rent.[2]

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[1] Cf. The Environmental Pollution Panel, Restoring the Quality of Our Environment, (The White House: The President's Science Advisory Committee, November, 1965), pp. 17-18. Abundant material relating to the establishment of air pollution control standards is available in the monthly issues of The Air Pollution Control Association Journal.

[2] Allen V. Kneese in his The Economics of Regional Water Quality Management, (Baltimore: The Johns Hopkins Press, 1964), pp. 82-85, argues that in a static world a charge is generally to be preferred to a standard because it often requires less information and because it offers the emitter an incentive to take action down to a zero level of emissions. But, with respect to the first supposed advantage, Kneese seems to assume implicitly that a standard specifying the required state of the receiving medium has already been (arbitrarily?) established. The charge is then simply manipulated in a more or less iterative manner until such time as the collection of emitters are induced to meet the standard by the least cost means.

Even in a static world of perfect certainty, the employment of an optimal emitter charge requires that the control authority determine individual receptor damage cost functions and individual emitter cost-savings functions, somehow decide how to aggregate the individual functions properly, equate the marginal forms of the aggregate functions, and impose the price which is arrived at for the use of the air resource upon emitters and/or receptors so that they will be induced to act in a manner bringing about the maximization of the air resource's rent. Similarly, in order to employ the optimal standard, the control authority goes through the same routine of determining individual receptor and emitter damage cost and cost-savings functions, summing over them, and equating the marginal forms of the summations. At this point, however, rather than bothering to establish a charge which will induce the receptors and emitters to act in the desired manner, our all-knowing air pollution control authority simply instructs (spelled *orders*) the receptors and emitters to act in the manner they would voluntarily have chosen to act with the imposition of the optimal charge. Thus, though

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As for the second supposed advantage, one might note that just as the charge by itself, no matter how far from being optimal, gives the emitter an incentive to take action down to a zero level of emissions, it also allows him to pay the charge up to a level closely approximating his maximum potential emissions. There is no *a priori* reason to think that whatever benefits are supposed to be associated with the former would occur with greater frequency and in greater magnitude than would whatever costs are associated with the latter. In summary then, the only inherent advantage in a comparative static world for the charge relative to the standard is some sort of psychological advantage: people are perhaps more likely to allow a price to be adjusted in accordance with changing conditions than they are a standard which, because it was set by "scientists," supposedly has the immutable "truths" of the physical world embedded in it.

the illusion of voluntarism present with the use of the emitter charge may have some political efficacy, this illusion can hardly be said to be a valid basis upon which to make an economic distinction between the effluent charge and the effluent standard. Any valid economic distinction, if there is one, must be found in the ability of the standard or the charge to maintain some allocation at least approximating maximization of the air resource's rent.

Realizing perhaps that analytically speaking the economically efficient emitter charge and the economically efficient emitter standard amount to the same thing in a world of statics and perfect certainty, the economist in contrast to the engineer or administrator, has chosen to busy himself discussing the necessity of imposing restraints upon the initial perpetuators of negative externalities. That is, in the air pollution case the economist has mainly discussed the relative merits, in the context of the criteria of Paretian efficiency, of the emitter charge. That to which the merits of the emitter charge are held to be relative is the absence of an emitter charge.[3]

The major point upon which the aforementioned debate among economists turns is the importance of barriers to trade between and among the offended and the offenders. Those who consider those barriers mentioned in Chapter II to be low and even nonexistent have been called the "modern-old" group, while those who consider the barriers to be high and even insurmountable under any and all conditions have been called the "modern" group.[4] The former have placed a great deal of emphasis upon the entirely correct point that externalities can be traded, but, due perhaps to the drastic simplifying assumptions necessary for the rigourous development of their models,[5] they have generally neglected the point that some means for trading must be made available; or, if available and not used, some constraints must be added to and/or deleted from the system so as to make it worthwhile to all contending parties for trading to take place. In contrast, the "modern" group has placed nearly all its emphasis upon those barriers to trade set forth in Chapter II and the supposed impossibility of adequately removing, climbing over, or going around these barriers. Basically, the "modern" group has emphasized the need for some continuing exogenous application of constraints in the form of emitter charges and/or standards. However, this emphasis has often blinded them to the fact that such application because of the trading opportunities, i.e., gains from trade, which it brings into existence can generate externalities itself. Thus in spite of the appearance which the emitter charge or emitter standard gives of being a simple and direct form of air pollution control, it is actually a very complex means operating perhaps primarily on emission volumes but with possibly important and usually unintended secondary effects on the areal and temporal distributions, numbers, and even the types of emitters and receptors. The application of a charge or a standard, though it appears to be clean and neat and readily handles the physical problem of placing some limitation upon the volume of pollutant emissions, can and often will produce secondary reactions that can cut very deeply into the economic gains justifying its original imposition. On the other hand, the insistence of the "modern-old" group that externalities are economic goods which can be and actually are traded does not constitute adequate grounds for denying the possibility of the continued existence of negative externalities, for it fails to recognize that trade takes place only to the extent that insurmountable barriers to trade are not present.[6] When these barriers to trade are removed or reduced, substantial new potential gains from trade can be generated and made visible.

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[3] There has been some controversy among economists as to the efficacy of the emitter charge relative to the emitter payment. Cf. *Ibid.*, pp. 90-98; and M. I. Kamien, *et. al.*, "Asymmetry between Bribes and Charges," *Water Resources Research*, 2 (First Quarter, 1966), pp. 147-157. Essentially, the discussion seems to be a debate about the proper distribution of property rights, for it really amounts to a question of whether one should bribe the emitter and tax the receptor (the payment) or tax the emitter and bribe the receptor (the tax). Or, if one instead prefers to take the point of view that the air resource initially belongs entirely to the emitter, then the alternatives become tax the emitter and bribe the receptor (the payment) versus bribe the emitter and tax the receptor (the tax).

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[4] The "modern" and "modern-old" distinction is due to Stanislaw Wellisz. See his "On External Diseconomies and the Government-Assisted Invisible Hand," Economica, 31 (Nov., 1964), pp. 345-362.

[5] Among the most important of these assumptions are (1) that the externality in question is divisible so that distinct and separate units can be assigned to individual entities; (2) that if the externality is relatively indivisible the size of the affected group is small; and (3) that there are no substantial communications or transactions costs.

Since taking without qualification the "modern-old" group's emphasis upon the fact that externalities are economic goods which can be traded means that no constraints need be placed upon the operation of the market, this approach can be readily dismissed as offering little assistance to the amelioration of an air pollution problem which does exist. It therefore is valid in what follows to dismiss the "modern-old" school and to devote attention entirely to the major suggestion offered for the economically efficient control of air pollution by the so-called "modern" school. Nevertheless, the approach of the "modern-old" school cannot be completely dismissed for its insights do lend substantial assistance to an understanding of the proposals of the "modern" school.

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[6] An artical typical of the "modern" group's approach is Francis M. Bator's "The Anatomy of Market Failure." The Quarterly Journal of Economics, 72 (Aug., 1958), pp. 351-379. A good representative of the "modern-old" group is R. H. Coase's "The Problem of Social Cost," Journal of Law and Economics, 3 (1960), pp. 1-44.

As has been previously noted, that control proposal of the "modern" school which has been accorded the greatest general favor among economists is the emitter or effluent charge. Ideally, this charge would be levied upon the emitters at that level which would tend to equate the present value of receptor marginal damage costs to the present value of emitter marginal cost savings. Supposedly, the nature of the allocation of the air resource following from the imposition of this optimal charge would not differ regardless of whether or not the receptor was compensated for his loses or whether or not any constraints were imposed upon the avenues of action open to the receptor.

Let us take up the compensation question first. Whenever or wherever a policy proposal involving some economic question has been based upon the taxation of one or more of the embraced parties, there has been a nearly universal tendency to assume that whatever revenues are collected simply shoot off into the farthest reaches of space, are dropped or thrown into some bottomless pit, or are always devoted to some worthy cause whose value has been, is, and always will be nearly infinite. Due to this rather difficult to understand traditional abstraction from the public expenditure side of taxation questions, the lump sum tax has generally been considered to be the optimal form of tax in that it supposedly is neutral, i.e., it supposedly does not affect allocation because the value it assumes is entirely independent of any decision variable in the system. But this view considers only one side of the question. Conceivably, any type of tax could increase the degree to which a Paretian optimum is approximated if the public expenditure of the tax revenues resulted in a net improvement in welfare over and above the improvement in welfare resulting from the supposedly neutral effects of a lump sum tax considered only from the imposition side of the question.[7] Of course, if one is dealing with a local air pollution problem and if the revenues collected from an emitter charge are to be spent on a national basis, the effect on the decision parameters of the local parties would be minimal. One would therefore be entirely justified in abstracting from any discussion of what happens to the revenues that are collected.[8] However, a failure on the part of many writers to perceive that this implicit assumption was necessary and was being made in all such discussions usually hid from them the fact that on the local level the pattern of expenditure of these tax revenues could make a substantial difference in the decision parameters of the affected parties. The most notable result of this failure has been an assertion by the most widely read writer on the economic aspects of environmental quality problems that "efficient results from a system of charges on the waste discharger do not depend upon payment of compensation to the 'damaged' party."[9]

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[7] This point has been made by James M. Buchanan in his Fiscal Theory and Political Economy, (Chapel Hill: The Univ. of North Carolina Press, 1960), pp. 1-23.

[8] In all the concern in the literature with the excess burden aspects of non-neutral forms of taxation, it seems to have been forgotten or perhaps never even recognized that a non-neutral tax is as likely to generate an excess benefit as an excess burden. For example, the revenues collected from a non-neutral tax might be employed to replace taxes which would otherwise have to be imposed for the provision of public goods. Or, rather than always starting from the premise that all the relevant Paretian conditions are being fulfilled, we might assume when discussing the nature of an optimal tax that some of these conditions are unfulfilled. The excess benefits generated by the non-neutral tax would then be the gains accruing due to the fulfillment of the Paretian conditions. Just such an approach appears to be the unrealized basis of proposals for taxing negative externalities and subsidizing positive externalities. The point made in this footnote is therefore little more than a point in semantics.

The incorrectness of the immediately preceding statement is easily shown even when bargaining or trading and conjectural variations between emitters and receptors is not allowed or is impossible. The following example shows that given the usual assumptions underlying the Paretian conditions, the value of total output will be less when the receptor is not provided compensation than when he is provided compensation.

Suppose the receptor firm possesses a bundle of non-air inputs, X, which it consistently combines in optimal proportions. As eariler noted, the receptor would find it worthwhile to accept payment from the emitter for permission to release pollutants into the atmosphere so long as the additional value of the payments was greater than the value of the additional damages. Though the air pollution control authority, since we have disallowed the possibility of negotiations between emitters and receptors, must act for the receptors, let the receptor "potential emissions avoided" be denoted by E. The fact that the receptors or rather the control authority acting in the receptors' stead holds the rights to these potential emissions means, of course, that the emitter will be unable to use them. They therefore are a positive economic input from the receptors' point of view.

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[9] Kneese, op. cit., p. 58.

Suppose that before the imposition of the effluent charge upon the emitter, the maximum potential emissions the individual receptor's foregone investment opportunities could have enabled him to avoid is given by the point C on the E axis of Figure 13.[10] That is, C gives the amount of potential emissions the emitter's actions enabled the receptor to avoid. Similarly, the point A on the X axis shows the maximum quantity of the X input bundle the receptor's alternative investment opportunities would have allowed him to purchase. The reasoning behind the shapes of the isoquants is the same as that explained for Figure 7 in Chapter IV. Since we assume that the provision of C of E does not involve the expenditure of any of the receptor's funds, he is able to use all his funds for the purchase of the input mix X. Thus he can purchase A of X, reaching, given C of E, the Y_1 isoquant.

Now presume that with the imposition of the optimal effluent charge upon the emitter, the amount of potential emissions the receptor can now avoid increases from C to D. The imposition of the charge has caused

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[10] If the emitter was completely unconstrained with respect to the amount of pollutants he could release, potential emissions would be equal to actual emissions. That is, the point C would be located at the origin, indicating that the receptor was completely unable to avoid any emissions. We assume here, however, that the threat of legal action and a certain healthy respect for public opinion prevent the emitter from treating the air as a completely free good. Similarly, when referring to Figure 13 it will be assumed that the imposition of an effluent charge in no way diminishes the threat of legal action nor the emitter's respect for "public opinion," whatever that might be.

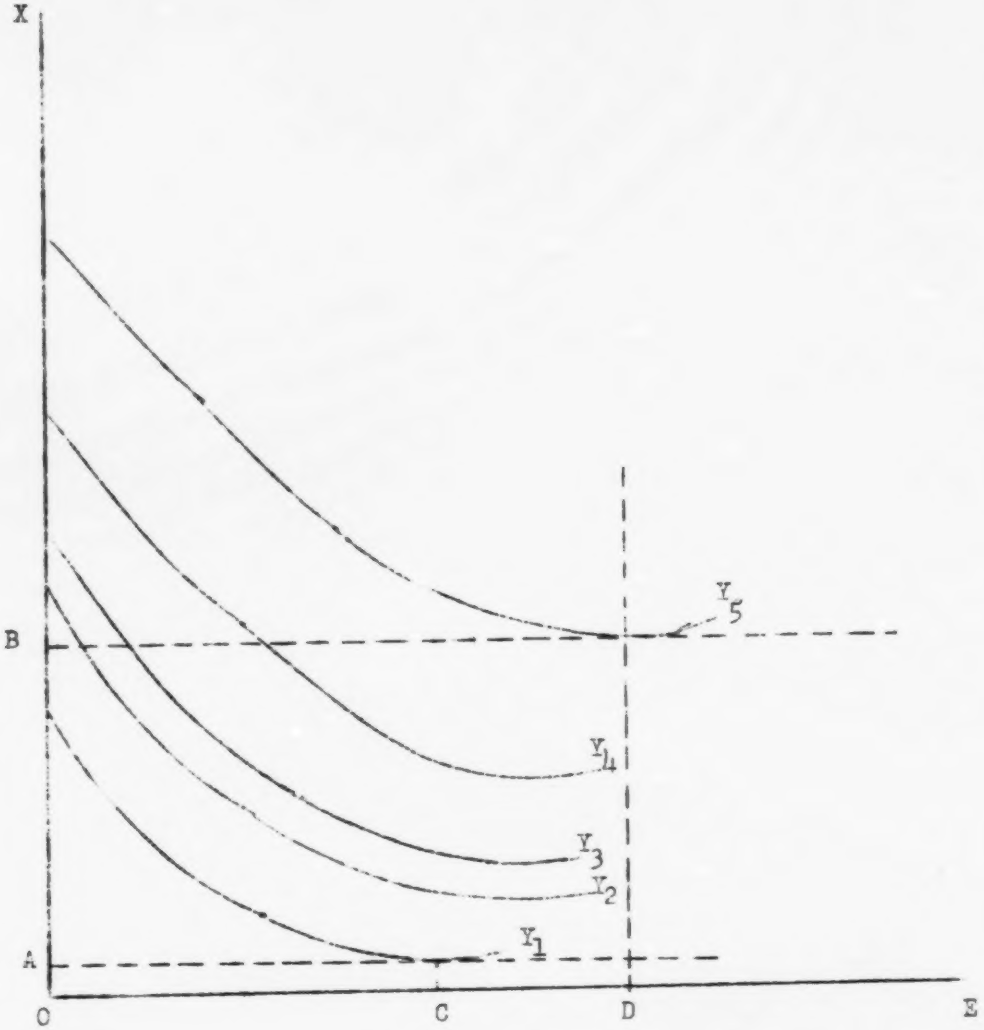

FIGURE 13

EFFECT OF RECEPTOR COMPENSATION UPON RECEPTOR OUTPUT the emitter to reduce the volume of pollutant materials he releases into the atmosphere, with the result that the pollutant fumigations or emissions avoided by the receptor increase from C to D. But the provision of this extra freedom from pollutant fumigations does the receptor no good because he is still able to purchase only A units of the input mix X.[11] He is unable therefore to move out beyond the Y_1 isoquant, i.e., he is unable to increase his output in spite of the greater cleanliness of the atmosphere.

Now, with the imposition of the emitter charge, if it is assumed that the dollar equivalent of the distance AB is the money the emitter pays to the control authority to be allowed to release an amount O-OD emissions, it is easily seen that the payment of this money to the receptor in the form of compensation for the damages he suffers will enable that receptor to reach a higher isoquant than before, the Y_5 isoquant. Without compensation, the maximum quantity of the X input bundle the receptor could purchase was OA, regardless of the extent to which he was allowed to and/or was able to avoid emissions. However, with compensation he is now able to employ a greater quantity of non-air inputs and reach a higher level of output for any given quantity of emissions than he could without compensation. Thus with compensation, the welfare of at least one party, the receptor, is unambiguously increased without any other party being made worse off. Less pedantically, receptor output is increased at no cost to anyone, assuming of course that the revenues collected from the charge would otherwise disappear down a bottomless pit, or assuming that prior to the provision of receptor compensation the world was in a perpetually Paretian optimal state except for the fact that the emitter was imposing too many uncompensated damages upon the receptor.

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[11] Receptor opportunities to vary the proportions of X or to substitute for X are assumed to be absent.

That the result of Figure 13 is not dependent upon the absence of receptor substitution possibilities is easily shown with the aid of Figure 14. In Figure 14, X_2 is presumed to be an input relatively insusceptible to pollutant fumigations while X_1 is an input relatively susceptible to pollutant fumigations. The collection of isoquants represents the technical substitution possibilities open to the receptor after the imposition of an optimal effluent charge upon the emitter. Tangent to the Y_2 isoquant is drawn the isocost line, ZZ, representing the various combinations of X_1 and X_2 the receptor's financing arrangements permit him to purchase when he is to receive no compensation for his damages. Under these conditions, the receptor will employe e of X, and f of X_2.

Now assume that the receptor is compensated an amount per unit of pollutant fumigations imposed upon him equivalent to that price equating his marginal damage costs to the emitter's marginal cost-savings.[12] In Figure 14, these compensatory payments are presumed to move the isocost function from ZZ to Z*Z* because the compensatory payments permit the

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[12] We abstract from questions about the ex ante or ex post nature of the compensatory payment with respect to the receptor's selection of his input mix and with respect to the invasion of the receptor's property rights. For the classic treatment of the problems raised by these question, see J. F. Hicks, "The Four Consumer's Surpluses," The Review of Economic Studies, 11 (1943), pp. 31-41. For a very good recent treatment, D. M. Winch, "Consumer's Surplus and the Compensation Principle," The American Economic Review, 55 (June, 1965), pp. 395-423.

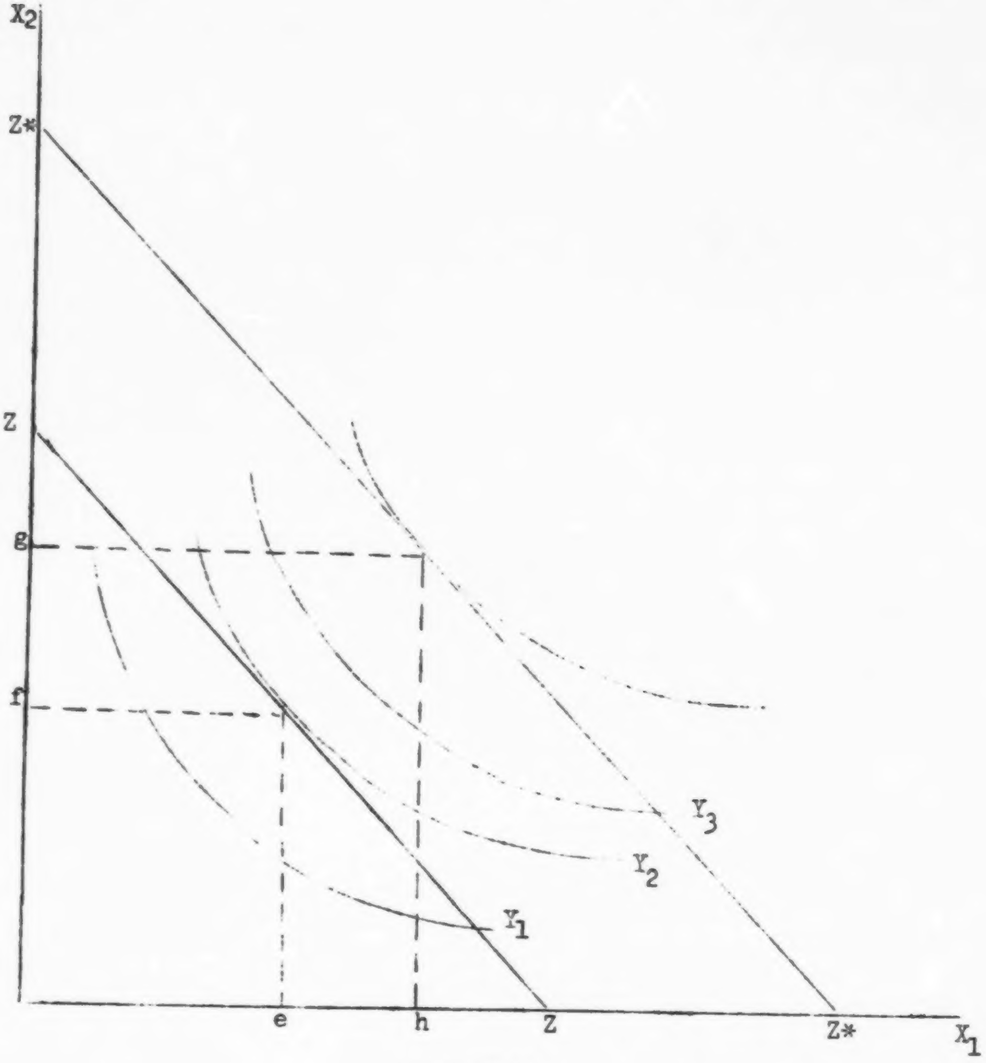

FIGURE 14

EFFECT OF RECEPTOR COMPENSATION
UPON RECEPTOR INPUT USE

receptor to purchase and use more of each input. Rather than using e of X_1 and f of X_2, he now uses h of X_1 and g of X_2. Again the receptor's output is unequivocally increased without any other party, including the emitter, being made worse off.

The results associated with Figures 13 and 14 are utterly dependent upon the assumption that the control authority has the ability to determine the input mixes and magnitudes the receptor would employ in a perfect market for emission rights. In a perfect market for emission rights, the receptor would carry out those temporal and physical input substitutions and scale variations minimizing his damage costs. That is, for each and every level of pollutant fumigations to which he is subject he would carry out those temporal and physical input substitutions necessary to minimize the extent to which his net revenues with positive pollutant fumigations differ from his net revenues with zero pollutant fumigations. If he actually has operative property rights in the air resource, he will carry out these substitutions and scale variations until the additional reduction in his net revenues caused by an added unit of pollutant fumigations, in spite of his efforts at minimizing damages, is equal to the amount the emitter is willing to pay in order to be allowed to release the additional pollutant unit. And if he does not have operative property rights, he will carry out these input substitutions until the additional cost of carrying out another physical and/or temporal substitution is equal, given the level of pollutant fumigations to which he is subject, to the value of the reduction in damage costs which the substitution brings about.

However, because of the practical difficulties involved for the control authority in specifying the most efficient physical and temporal substitution possibilities available over time for receptors, one specific input mix and magnitude is likely to be employed as the base for the determination of receptor damages. Since property rights in the air resource are supposedly exclusively the receptor's, an often suggested and likely candidate for this base is the receptor input mix and magnitude prevailing before the advent of pollutant fumigations. That is, air pollution damages would be calculated in terms of the response of receptor output to air pollutant fumigations, where that output is a function only of the receptor input mix and magnitude prevailing before the initiation of air pollutant fumigations. No attempt would be made to take into account the possibilities for damage cost minimization by temporal and physical input substitution and variations in scale the receptor would take advantage of in a perfect market for emission rights. It follows, therefore, that the damages the receptor appears to suffer when his possibilities for temporal and physical input substitution and scale variation are not taken into account will be greater than when they are taken into account. The result is that the compensation per unit of pollutant fumigations the receptor receives for damages when the "clean air" input mix and magnitude is taken as the base for damage calculation is greater than the compensation he would receive for damages in a perfect market. In fact, the compensation the receptor receives per unit of pollutant fumigations will be greater, the total damages he suffers will be less, and the pollutant fumigations to which he is subjected will be fewer. This situation is depicted in Figure 15.

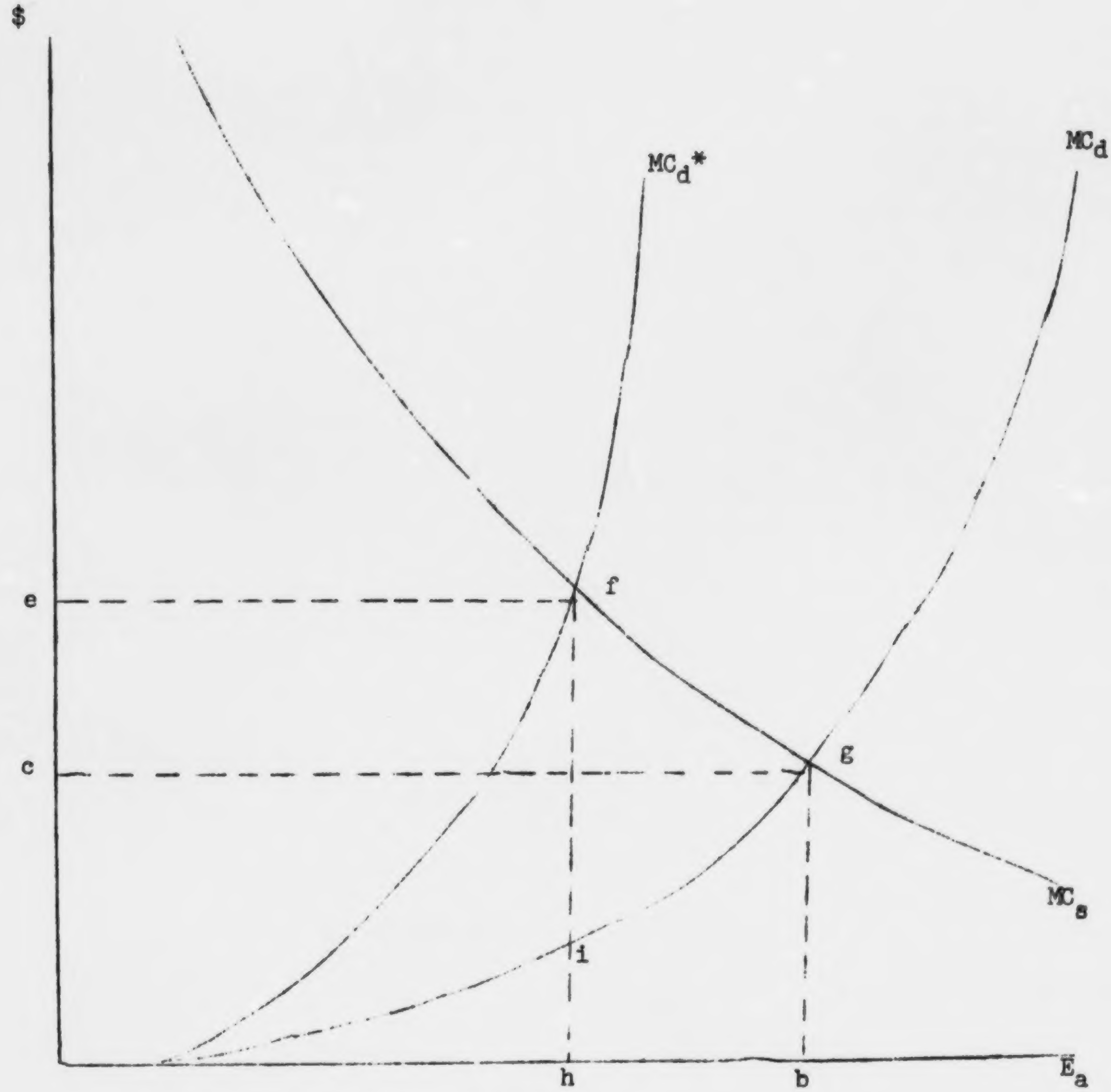

FIGURE 15

EFFECTS OF ALTERNATIVE BASES
FOR THE CALCULATION OF
RECEPTOR DAMAGE COSTS

In Figure 15 is shown the responsiveness of receptor marginal damage costs in a perfect market, MC_d, receptor marginal damage costs when only the "clean air" input mix and magnitude is available, $MC*_d$, and emitter marginal cost-savings, MC_s, to variations in actual pollutant fumigations, E_a. The MC_d function is an envelope function made up of the least cost receptor input mixes and magnitudes for various levels of actual pollutant fumigations. In a perfect market for emission rights with operative receptor property rights in the air resource, the market price which would be established for the right to emit a unit of pollution would be c, and the number of units released would be b. This price and quantity ensure that the sum of receptor damage costs and emitter cost-savings foregone is minimized. However, when the receptor's "clean air" input mix is used as the basis for calculating receptor damage costs, the charge imposed upon the emitter for each unit of pollutant material he releases is increased to e, the amount of pollutants he does release is reduced from b to h, the total damages borne by the receptor are reduced by bhig, and the total costs borne by the emitter increase by bhfg. Since bhfg is greater than bhig by ifg, the additional costs imposed upon the emitter by the use of the "clean air" receptor input mix and magnitude are greater than the additional benefits in the form of damage cost reductions accruing to the receptor.

It should be noted that the slope of the marginal cost-savings function and the difference between the slopes of the "clean air" and perfect market marginal damage cost functions determine the extent to which the use of the "clean air" input mix and magnitude will fail to to minimize the sum of receptor damage costs and emitter cost-savings. As the MC_s function becomes more nearly vertical, i.e., as the emitter's cost-savings become more responsive to increases in actual emissions, the area ifg becomes smaller. When this MC_s function is infinitely responsive to further increases in actual emissions, it makes no difference to the minimization of the sum of emitter cost-savings and receptor damage costs whether the MC_d or the MC^*_d function is employed to calculate receptor damages. Similarly, the less the difference in the slopes of MC_d and MC^*_d, the less the magnitude of ifg and the greater the grounds for indifference as to which input mix and magnitude is used for calculating receptor damages.

The use of effluent charges lacking optimality is likely to be a quite typical feature of any attempt actually to employ the charge. Even when an air pollution control authority is initially able to determine the receptor perfect market input mixes and magnitudes for varying levels of pollutant fumigations over some one interval of time, it is doubtful that the authority could keep track over time of the shifts in the MC_d function. In the absence of the ability to take these shifts into account, resort is likely to be had to determining receptor damages by observing existing receptor input mixes and magnitudes. Damages would then be measured in terms of the difference in the value of receptor output for the observed input mix and magnitude with and without pollutant fumigations. In circumstances like these, some caution is warranted in the employment of receptor compensation.

In Figure 16, as before in Figure 14, the isoquant surface represents the technical substitution possibilities open to the receptor after the imposition of an effluent charge upon the emitter. However, this time the effluent charge is not necessarily optimal, since the base receptor input mix and magnitude employed for the calculation of receptor damages is the observed input mix and magnitude. The isocost function WW, again representing the various combinations of X_1 and X_2 the receptor's financing arrangements permit him to purchase when he receives no damage compensation, is drawn tangent to the Y_2 isoquant. Without being compensated for the damages imposed upon him, the receptor will employ i of the relatively pollution susceptible input, X_1, and j of the relatively pollution insusceptible input, X_2.

Now, if the receptor is compensated by an amount equivalent to the effluent charge for each unit of pollutant fumigations from which he suffers and if he knows that the level of this charge will continue to be based in part upon the difference in the value of his output with and without pollutant fumigations for the observed input mix and magnitude, he will employ k of X_1 and m of X_2. Though the compensation the receptor receives in Figure 16 can be and is used to purchase more of both X_1 and X_2, the compensation he actually does receive tends to reduce the effective price for him of the pollution susceptible input, X_1, relative to the price of the pollution insusceptible input, X_2. In Figure 16, this change in relative prices moves the receptor's isocost function from WW to WW*. This movement from WW to WW* takes place simply because the receptor knows that the input mix and magnitude the control authority observes will be the one it employs for the determination of receptor damages. Since the effluent charge imposed upon the emitter and therefore the receptor's compensation per unit of pollutant fumigations increases with increasing air pollution damages,

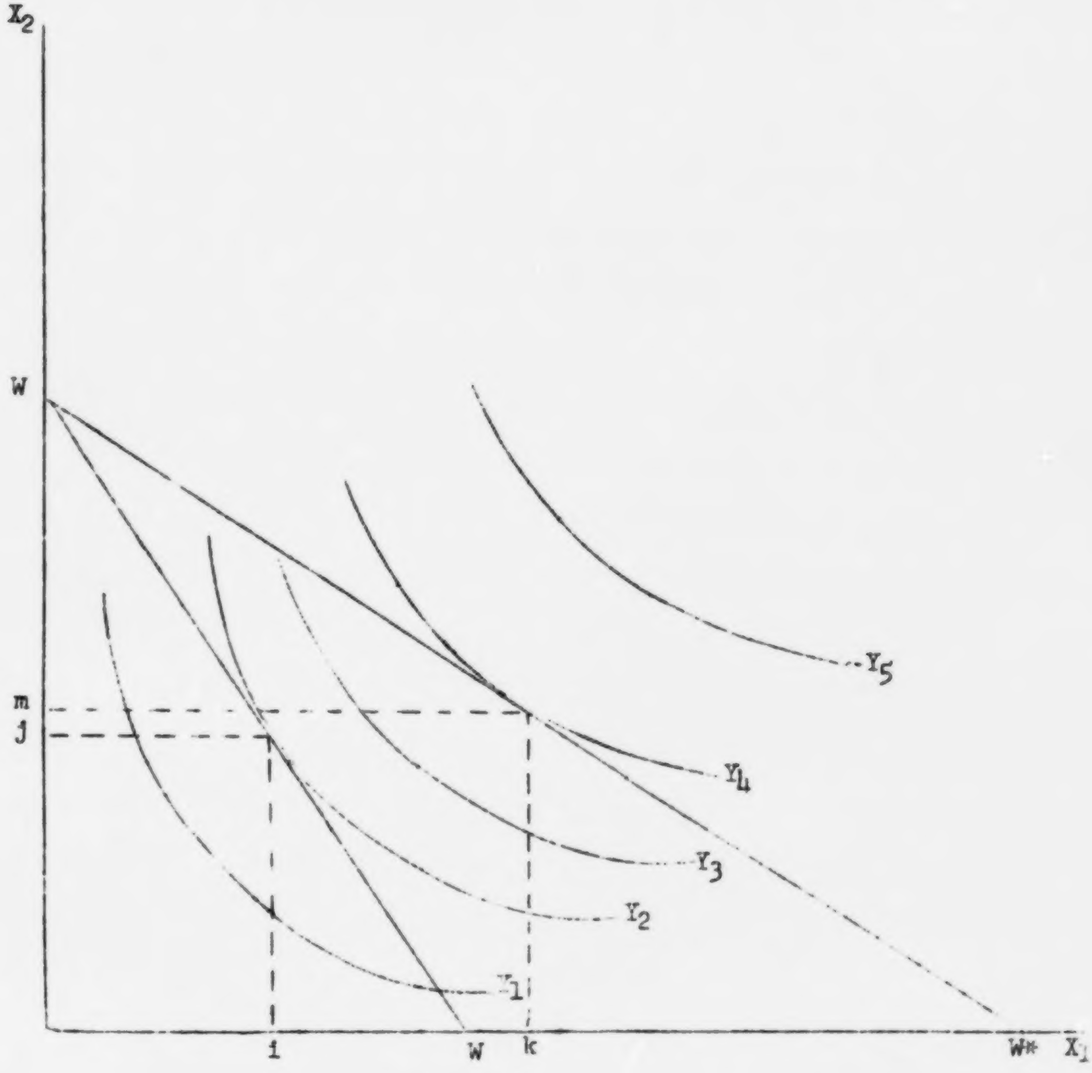
X_2
W
m
j
Y_1
Y_2
Y_3
Y_4
Y_5
i
W
k
W*
X_1

FIGURE 16

RECEPTOR COMPENSATION BASED UPON
OBSERVED DIFFERENCES IN RECEPTOR OUTPUT

the receptor will use the relatively pollution susceptible input, X_1, until the additional damage costs he suffers by its use are equal to the increase in his total compensatory payments. These total receptor compensatory payments will, in turn, be related to the responsiveness of the emitter's marginal cost-savings function to variations in "actual emissions." If the emitter's marginal cost-savings function is highly responsive to variations in actual emissions (if the MC_s function in Figure 15 approaches the vertical), then the receptor can employ large quantities of the relatively pollutant susceptible input to his advantage because the emitter will pay very high effluent charges rather than do without the right to release an emission unit. Conversely, if the emitter's marginal cost-savings function is quite unresponsive to variations in actual emissions, then total receptor compensatory payments will not increase very greatly with increased input pollutant damage susceptibility.[13]

Perhpas the major feature of the immediately preceding remarks is that the use of the nonoptimal emitter charge with provision for receptor compensatory payments in direct proportion to damages suffered can readily introduce reciprocal interdependence into an air pollution problem. Before the imposition of the nonoptimal emitter charge, receptor net revenues were, among other things, dependent upon the emitter's production and emission decisions. But, unless trade in externalities took place so that the emitter had to regard foregone receptor payments as an opportunity cost, the emitter's production and emission decisions were in no way influenced by the receptor. However, with the imposition of a nonoptimal effluent charge whose severity is to vary directly with the level of receptor damages, this one-way interdependency is no longer the case. Just as the emitter must now recognize that his production and emission decisions influence receptor production decisions, receptor production decisions will have an influence upon emitter production and emission decisions. But the fact that the receptor's actions now influence the emitter's production and emission decisions need not imply any exceptional adjustments in the manner in which the receptor goes about attempting to maximize the present value of his net returns. All that the receptor is doing in the material associated with Figure 16 is reacting rationally to the environment in which he finds himself: he reacts rationally to the pattern of pollutant fumigations and compensatory payments but does not intentionally attempt to change it.

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[13] With each new effluent charge and its associated quantity of actual emissions, a new set of technical input substitution possibilities--a new isoquant surface--will confront the receptor. Whether this new surface will involve increased or reduced opportunities to substitute the relatively pollution susceptible input is not evident.

All of the preceding remarks treat the receptor as rather a gentle soul, or perhaps as an idiot--a dunderhead, that is, they assume him to be so utterly stupid--or, more mildly, so passive--that given a particular volume of pollutant fumigations over some given interval of time, he will select that quantity and mix of inputs causing the present value of his net returns, psychic and/or pecuniary, to be maximized. It is not the assumption that the receptor will maximize the present value of his net returns which is of questionable vaildity, but instead that he will do so by taking the volume of emissions to be released over some time interval as being something he is unable to do anything about.

If the receptor is given the opportunity to be only partially successful in enforcing his theoretical property rights, the air pollution problem really reduces to one of determining the proper exchange process or system in a situation where a great deal of uncertainty exists in present circumstances, and unless carefully modified, will continue to exist in the future. The type of uncertainty being referred to is of course not so much that usually classified under a complete lack of probablistic knowledge regarding the interactions between and among present and future production possibilities, states of technology, random acts of nature, and market conditions; but rather that type usually included under strategy or game problems in which all participants and actors in the system have brains they are not unwilling to use. The essence of this latter type of problem is captured by the point that the prospects faced by any one emitter or receptor are determined not only by that state of the ambient air the individual attempts to exploit to his advantage but also by the other air users who are the individual's opponents and who might explicitly and intentionally try to turn the world to his disadvantage while simultaneously trying to turn it to their advantage. In this latter sense, all the maneuverings which emitters and receptors may carry out amount to nothing more than their attempts to reduce the uncertainties surrounding their expectations about their reprecussions upon one another. Before the imposition of any nonoptimally based effluent charge upon the emitter, the receptor's net revenues were, among other things, a function of the emission decisions made by the emitter, but the emitter's emission decisions were not a function of the receptor's decisions about the inputs he would employ. With the imposition of the effluent charge, this one-way interdependency is no longer the case. The emitter's emission decisions are now dependent upon the receptor's production decisions and the receptor's production decisions are dependent upon the emitter's emission decisions. In a system in which the natural origin of property rights in the air resource is considered to be a complete lack of detrimental effects upon the receptor, the imposition of a nonoptimally based effluent charge upon the emitter can cause him to take into account the influence of his emission decisions upon the input mix and quantities selected by the receptor. And similarly, the system can cause the receptor to recognize explicitly that his decisions about input mixes and quantities have an influence upon the emitter's emission decisions: the emitter charge based on observed receptor damages gives the receptor an opportunity to impose negative externalities upon the emitter.

Given that the effluent charge to be imposed upon the emitter is to be based upon observed receptor marginal damage costs, it is not unreasonable to assume the receptor to be sufficiently intelligent to realize explicitly that by selecting certain mixes and quantities of pollution susceptible inputs, he can for any given level of emissions increase the total effluent charges the emitter must pay. That is, rather than decreasing his pollution susceptible base by substituting inputs which are quantitatively and/or qualitatively less susceptible to air pollution damages, or rather than trying to minimize the sum of his damage costs and foregone compensatory payments, he might actually increase the pollution susceptible base to the extent that he himself is taking short-term losses in order to impose upon the emitter what he thinks to be long term losses. Both receptors and emitters are able to manipulate the quantity of pollutant fumigations. The question ultimately becomes one of asking whether receptors and emitters are actually willing to play the passive unobservant roles assigned to them in most writings about control methods. As the Polk County case has shown, there are solid reasons for thinking that they are unwilling to do so, particularly if they have legal and political means available for applying pressures to the opposing party.

Though one cannot validly assert that the easy acceptance in most writings of the idea that the effluent charge equating marginal cost-savings to marginal damage costs for one or a small number of input mixes and magnitudes is the cause of the lack of attention given to the possibility of conjectural variations, any presentation attempting this equation must make the assumption, implicit or otherwise, that receptor and emitter net revenue maximization for a few input mixes and magnitudes is fully compatible with net revenue maximization when the possibilities for substitution and scale variation are abundant. An example of this lack of compatibility was pointed out in the material associated with Figure 16. Other examples of at least the partial absence of this compatibility come easily to mind when one party or the other is willing and prepared to bear short-term losses in order to acquire what it conceives to be long-term gains. So long as the party feels that the present value of what are thought to be the long-term gains outweighs the present value of the short-term losses, conjectural variations will emerge. The expected losses for any party using a strategy in which conjectural variations are involved would start at the point in time his strategy is initiated and would extend to the point in time the party in question expects the other party to give up or to accept the result the first party considers desirable. Similarly, the expected benefits of such a strategy would start at the point in time at which the other party is expected to give up and would extend to the time horizon of the party in question. Staying power or the amount of liquid resources each party can draw upon is thus likely to play an important part in determining the ultimate "winner." In any case, an inoptimal effluent charge based on observed receptor damage costs is unlikely to achieve even a stable situation in any reasonable time interval, for broad possibilities for receptor and emitter bargaining would remain and might even be created. Unless a control, whether it be a charge or a standard, is so perfect that it eliminates all visible gains from trade, continued bargaining will occur. The only way to prevent it is to outlaw bargaining.

The number of strategies and their variations which emitters and receptors can adopt is of course enormous. That strategy initially selected by the receptor involving the substitution of inputs highly susceptible to pollution for inputs which are less susceptible to pollution may necessitate a reduction in emissions by emitters. But, if the present value of the increase in costs imposed upon the emitter by the receptor's strategy is greater than the present value of the increase in long-term benefits to the receptor, then it will be worthwhile for the emitter to pay the receptor to stop exaggerating his damages or even perhaps to buy the receptor out. For that matter, if the emitter perceives that the receptor is taking steps tending to exaggerate long-term damages, it might even be worthwhile for the emitter to increase his emissions to the point where, due to having to pay the effluent charge, he is bearing short-term losses in order to acquire long-term gains. Were the emitter to employ such a strategy, the form of his long-term gains might be that he would no longer have to contend with the receptor: the receptor would be driven from the land. The emitter is likely to find a strategy such as this particularly appealing when any reductions in the level of his emissions require the installation of rather durable air pollution control equipment and/or changes in production processes which involve high capital costs and low operating costs.

Additional complications can readily be introduced. When several receptors and/or several emitters are present, circumstances in which one receptor pays another to employ a greater quantity of pollution susceptible inputs or one emitter pays another to increase his emissions are easily imaginable. The "free rider" problem would be less stringent here than usual, for it would often be to the advantage of any one individual in the receptor or emitter group to pay other individuals in that same group to act as he does. That is, the more individuals in the group who adhere to the same strategy the greater the net benefits accruing to any given degree of effort by an individual member of the group. For the individual receptor who exaggerates his damages and bears the short-term costs of doing so, the more the receptors who similarly exaggerate their damages, the greater the long-term net benefits the individual receives for any given level of foregone short-term net returns. And for the individual emitter who thinks it worthwhile to increase his emissions in the hope of driving receptors from the land, the greater the number of emitters who also see fit to increase their emissions, for any given level of individual emissions, the greater will be the damages imposed upon receptors.[14] In short, the emitter gets more for his money when other emitters help him.

If one wishes, he can introduce something approximating an infinitude of complexity by allowing some differences among individuals in a situation in which groups of emitters and/or receptors are present. For example, because an additional unit of receptor damages must necessarily be the joint responsibility of all emitters, individual emitters whose emissions are substantially lower than other emitters but whose incremental control expenses are quite high might find it worthwhile to pay emitters whose emissions are high but whose incremental control expenses are low to reduce their emissions. In all these situations in which conjectural variations might arise, nearly all that information a control authority could obtain about emitter cost-savings and receptor damage costs would be seriously biased. That is, the observations would bear only a highly superficial, if any, resemblance to those derived from the receptor and emitter input mixes and magnitudes employed in a perfect market for emission rights.

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[14] For presentations of some of the conditions under which these "coalitions" are likely to form, see M.A. Kafoglis, Welfare Economics and Subsidy Programs, (Gainesville: The University of Florida Press, 1961), 83 pp. and James M. Buchanan, and M.A. Kafoglis, "A Note on Public Goods Supply," The American Economic Review, 53 (June 1963), pp. 403-414.

Finally, as noted immediately above, the conclusion of many situations in which conjectural variations are found is that one party or the other is utterly and thoroughly routed. In an air pollution situation, a conclusion of this sort would require the demise of either the receptors or the emitters. In effect, a more or less nongovernmentally instigated zoning would occur in which either the receptors or the emitters would move to a new location. The old location would be devoted exclusively to the uses of that group achieving final victory.

A conclusion in which one group must depart so that the other group may have exclusive use rights is in close accord with the often advanced argument that specific areas should be devoted solely to waste disposal while others apparently should have uncorrupted and pristine pure air.[15] However, the economic validty of this specialization proposal requires the fulfillment of at least one of two rather special and narrow assumptions. The first required assumption is that the emitter use and the receptor use be entirely incompatible in a physical sense. That is, the smallest possible presence of the emitter use completely shuts out any physical presence of the receptor use; or the smallest possible presence of the receptor use wholly thwarts and frustrates any physical possibility of the emitter use. If this first assumption is fulfilled, the economic analysis of the pollution problem cannot be considered too difficult for all one needs to do is select that use which produces the greatest net benefits. Strictly dichotomous situations present no real difficulties to economic decision-making.

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[15] Cf. Kneese, op. cit., pp. 145-150; and Committee on Pollution, Waste Management and Control, Publication 1400, National Academy of Sciences - National Research Council, (Wash. D.C.: Printing and Publishing Office, National Academy of Sciences, 1966), p. 48.

The second assumption required by the specialization proposal--that assumption which must be fulfilled if the first is not fulfilled--is that whenever two or more uses of a given space are in some degree physically competitive, the net returns from one use must outweigh the net returns from any and all other uses for each and every conceivable scale of all uses. This is certainly a rather stringent requirement one suspects could be fulfilled if and only if categories of use were defined in a rather broad and loose manner. Economists have had a quite unfortunate traditional attachment to the assumption that once the "internalization of externalities" takes place, the resulting individual entity (firm) will automatically act in the most efficient manner.[16] But the area specialization proposal avoids the necessity of any economic analysis at all, whether that analysis deals with allocative efficiency in terms of market structure or whether it also considers internal firm efficiency. On the one hand, in accordance with the usual assumption, the fact of internalization provides the means of avoiding asking any questions about just how the single entity which remains is to decide how to use the air resource. On the other hand, the provision of separate, non-joint, identifiable facilities for the opposing interests neatly avoids the difficulty of determining the framework in which the interests can be allowed to compete with each other.

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[16] For the basic work giving this view of the firm as the "internalizer of externalities," see R. H. Coase, "The Nature of the Firm," Economica, 4 (1937), pp. 386-405. A recent article has been critical of the absence of attention to internal firm efficiency and the supposedly excessive attention given to market structure fostered by this absence of attention. See Harvey Leibenstein, "Allocative Efficiency vs. X-Efficiency," The American Economic Review, 56 (June 1966) pp. 392-415.

Rather than basing their arguments on the quite shaky and tenuous foundations set forth in the previous two paragraphs, it might well be that the proponents of area specialization are simply somewhat timid or reluctant to admit the indeterminancy and uncertainties involved in the air pollution problem. In fact, if the uncertainties surrounding the difficulties and costs associated with (1) the acquistion of relevant information, (2) the policing arrangements for the policies decided by or imposed upon the opposing parties, and (3) the making of decisions when conjectural variations are involved--if all those difficulties and their associated costs set forth in this and earlier chapters are taken into account, then area specialization might often be an economically justifiable means of coping with air pollution. The area specialization solution will be an economically viable and valid means of air pollution control whenever the sum of perfect market damage costs and cost-savings, plus the costs associated with the three aforementioned confounding uncertainties are greater than the losses due to area specialization and caused by deviations from perfect market damage costs and cost-savings. But since these perfect market damage costs and cost-savings are themselves uncertain or at least difficult and costly to ascertain, when and where area specialization becomes a valid approach is itself uncertain. Area specialization then becomes nothing more than an extreme form of an arbitrary air pollution control standard in which the level of pollutant emissions allowed in one locale is zero or near-zero and in another area unlimited. Whether a standard this severe is necessary in order to ameliorate the uncertainties permeating air pollution problems is open to question. If a less severe standard not calling for complete separation of the opposing parties has a smaller sum of what appear to be perfect market receptor damage costs and foregone emitter cost-savings, and if the level of certainty is the same as that under area specialization, then the less severe standard must be economically superior.

II. THE IMPLICATIONS OF UNCERTAINTIES

Given the difficulties and costs involved in policing, information gathering, and taking into account conjectural variations, any attempt to impose an optimal effluent charge upon an air pollution problem may simply be another example of what one economist is reported to have termed the economics profession's " 'irrational passion for dispassionate rationality.' "[17] It is not at all apparent that the rent accruing to the air resource with an inoptimal charge based upon observed receptor damage costs and emitter cost-savings will be any greater than that for other types of control devices in which policing costs and information costs are minimal and opportunities for conjectural variations do not arise. To the extent that the inability of the air pollution control authority to determine over time the perfect market cost-savings and damage cost functions and to operate on the basis of them gives rise to increased emitter and receptor uncertainty about future states of the air resource, any control device which reduces this uncertainty would be increasing the air resource's rent. That is, if uncertainty generates inefficiencies in the use of the air resource, any control device which provides greater predictability promotes efficiency. Greater predictability would mean that the need of receptors and emitters for information on what the control authority intends to do is reduced, that the need of the control authority for information on what receptor and emitter plans are would be less, and that the need for control authority policing of receptor and emitter responses would be decreased.

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[17] William J. Baumol and Richard E. Quandt, "Rules of Thumb and Optimally Imperfect Decisions," The American Economic Review, 54 (March, 1964), p. 23.

Uncertainty is generally defined as the variance and/or some other moment of the expected frequency distribution of the values to be assumed by a parameter over some future time interval.[18] Uncertainty can therefore be said to involve the absence of complete knowledge about the relationship or association between the values assumed by various parameters in time t and the values these same parameters will assume in t + n, where n is greater than zero. The problem faced, for example, by the receptor uncertain about the levels of air pollutant fumigations to which he will be subject is then one of selecting an input mix and magnitude[19] minimizing the extent to which the present value of his expected net revenues is less than what the present value of his expected net revenues would be when he knows precisely the levels of pollutant fumigations to which he will be exposed. Unable to predict exactly the forthcoming level of pollutant fumigations, he must respond in that manner giving him the greatest likelihood of minimizing his losses.

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[18] For a discussion of the completeness of the various definitions or measures which have been suggested, see Marcel K. Richter, "Cardinal Utility, Portfolio Selection, and Taxation, "The Review of Economic Studies, 27 (1959-60), pp. 152-155.

[19] He must also select an output mix if quality variation is at all important.

Usually under these circumstances, the advice given to the receptor is to have and to maintain operational flexibility. Though the meaning of the term is sometimes lacking in clarity,[20] it is apparent that it at least consists of a set of current actions permitting efficient later responses. If the receptor's response to the uncertainties he faces must consist of a temporal sequence of decisions about the inputs he will employ and/or the outputs he will produce, then the term's meaning is clearly to be found in some positive reduction in the interdependencies between and among inputs and outputs of different dates. Complete independence of dated inputs and outputs, i.e., complete flexibility, would therefore inply that their optimal levels at $t > 0$ are independent of their optimal levels at $t = 0$.

The desirability of flexibility for the receptor will vary directly with the length of the time interval between t and $t + n$ and with the rate as a function of the passage of time that predictability of the $t + n$ environment increases. If predictability does not increase as $t + n$ approaches, then receptor attempts to provide flexibility can serve no rational purpose. The use of flexibility criteria must mean that the receptor feels he will learn more about the environment in which he will have to operate as of a given date as that date approaches.

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[20] Probably the best known pieces in this area are the following: (1) A. G. Hart, "Anticipation, Uncertainty, and Dynamic Planning," Studies in Business Administration, 11 (1941), 98 pp.; (2) A. G. Hart, "Risk, Uncertainty, and the Unprofitability of Compounding Probabilities," in William Fellner and Bernard F. Haley, eds., Readings in the Theory of Income Distribution, (Homewood, Ill,: Richard D. Irwin, Inc., 1951), pp. 547-557; (3) Thomas Marschak, and Richard Nelson, "Flexibility, Uncertainty, and Economic Theory," Metroeconomica, 14(April-August-December 1962), pp. 42-58; and (4) George Stigler, "Production and Distribution in the Short Run," Journal of Political Economy, 47 (June 1939), pp. 305-327.

The receptor's reduction of temporal interdependency by the provision of flexibility can assume three forms. First, the receptor can maintain a greater than optimal quantity of capital inputs in order to provide himself in the form of excess productive capacity with the opportunity to shift from the production of one type of output to another, or, in the case of rather rigid technical coefficients of production, to change quickly the amount of any one type of output he produces. Second, he can employ adaptable capital inputs, i. e., capital inputs whose intensity of use can easily be varied. This attribute simply means that the capital input/current input coefficient of the production process the receptor employs is not fixed or rigid. Third, the receptor can employ inputs having a relatively short useful life under a wide range of pollutant fumigation conditions.

Each of the preceding alternatives requires that for a given unit cost of production the receptor sacrifice some higher output level over some relatively short time interval in order to ensure a high probability of achieving some lesser output level over each of several similar time intervals. Given that the receptor does not find it expedient to produce another type of output, his cost of flexibility is the value of the difference, if any, between potential output under certainty about the actual outcome and actual output under uncertainty about the actual outcome. In short, the economic necessity of the receptor maintaining flexibility is a loss attributable to expected variations in the levels of pollutant fumigations--not to the simple existence of pollutant fumigations. And these expected variations in pollutant fumigations are due to uncertainty about the type and nature of the information the control authority will have available, the extent to which the control authority will use this information, the extent to which it will attempt to enforce the decisions it makes on the basis of its imperfect information, and the nature of the responses of emitters and other receptors, given the existing and expected degrees of enforcement, to these decisions.

As an example let us assume that the receptor attempts to acquire flexibility by employing the second of the aforementioned three alternatives. That is, in order to be prepared for whatever level of pollutant fumigations might ultimately develop, he decides to employ adaptable capital inputs whose intensity of use can, by definition, easily be varied. In Figure 17, MC is assumed to be the receptor's supply function when he knows with certainty what the maximum quantity of pollutant fumigations in t + n will be. Though not readily adaptable to other levels of pollutant fumigations, the production process associated with MC is the best available for the level of pollutant fumigations which will ultimately occur. Given the level of pollutant fumigations which finally does occur in t + n, let MC* be the supply function for the production process having that degree of adaptability compatible with the extent of the receptor's uncertainty about the level of pollutant fumigations in t + n. Whatever the level of pollutant fumigations ultimately proves to be, MC* must lie above MC for some output interval because the latter has been defined as the supply function associated with the best available production process for that level of pollutant fumigations which will ultimately occur.[21] Though, as Figure 17 shows, the production process associated with MC* is not the least cost process of production for the level of pollutant fumigations which ultimately does occur, it is a lesser cost process than is the MC process for several levels of pollutant fumigations which, when the receptor looks toward t + n, have some positive possibility of occurrence. Given that uncertainty about the level of pollutant fumigations in t + n exists, MC* will be the same as MC if and only if the least cost processes of production do not vary with the level of pollutant fumigations.

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[21] The receptor firm is assumed to be unable to influence the prices at which it purchases its non-air inputs.

PP in Figure 17 is the demand function which the receptor firm faces for its output. With the level of pollutant fumigations which finally does prevail, the receptor will produce at the output level b; whereas with perfect certainty he would have been able to employ the production process associated with MC and produce at the output level c. The receptor firm producing at the output level b has as net revenues the area hPdg. If the production process associated with MC rather than MC* had been employed and the output level c was produced in t + n, the receptor's net revenues would be hPf. The difference is the area dfg, which gives the difference between the net revenues the firm could have made were it able to predict with certainty before selecting its production process what the maximum level of pollutant fumigations would be in t + n, and what its net revenues will actually be, given that it finds it most expedient to use the production process associated with MC*.

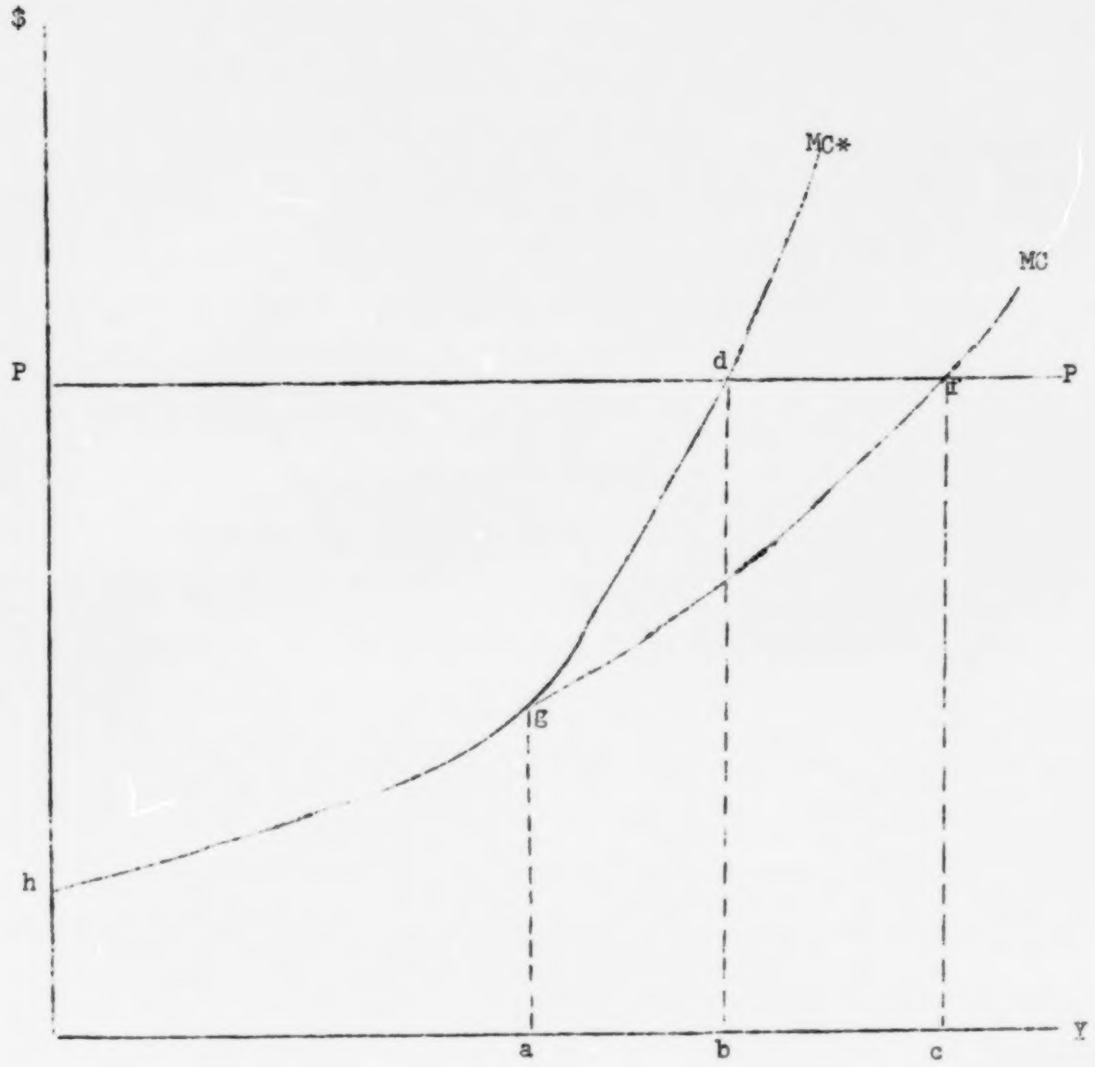
$
MC*
MC
P
d
f
P
g
h
a
b
c
Y

FIGURE 17

RECEPTOR LOSSES DUE TO UNCERTAINTY

The area dfg may be defined as the cost of uncertainty to the receptor.[22] If the demand function faced by the receptor is, as in Figure 17, highly price elastic, then optimum receptor output is highly sensitive to differences in the degree of certainty about what future pollutant fumigations will be. Furthermore, the difference in receptor net revenues between an output level that is optimal under conditions of certainty and one that is optimal under conditions of uncertainty is large. On the other hand, if the demand function faced by the receptor is steep, i.e., if it is relatively price inelastic, then optimal output is not very sensitive to differences in the production processes associated with optimal receptor responses to certain and/or uncertain future environments. Thus the slope of this price schedule is an indicator of the cost to the receptor of uncertainty. The greater is the slope of the price schedule--the less the competitiveness of the output market in which the firm operates--the less will be the reduction in the receptor firm's net revenues due to a given level of uncertainty about pollutant fumigations in t + n. Conversely, the greater the competitiveness of the output market in which the firm operates, the greater will be the reduction in the receptor firm's net revenues due to a given level of uncertainty. Thus in a situation where the receptor firms are unable to exert much influence over the prices they receive for their output, any control device which generates a good deal of uncertainty as to what levels of future pollutant fumigations will be will cause receptors to suffer deadweight losses they would not have suffered if they knew what pollutant fumigations were to be. Conversely, for a receptor firm operating in a quite imperfectly competitive output market, uncertainty about future levels of pollutant fumigations generates relatively small losses. In the Polk County situation, where the receptor firms were cattlemen and citrus growers able individually to exert little if any influence over the prices they receive, any uncertainty caused by the control authority's policies probably did generate some losses.

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[22] The same principles would apply to the emitter. Thus uncertainty about the permitted level of pollutant fumigations in t + n involves losses for emitters as well as receptors.

It is, of course, not only the receptor who will suffer from uncertainty about allowable future levels of pollutant fumigations, but also the emitter. The receptor will be uncertain about the marginal rates at which he will be able to substitute "actual emissions avoided" for his positive, non-air inputs, or what the marginal rates will be at which his non-air inputs can be substituted for each other. The emitter in turn will be uncertain about the marginal rate at which he will be able to substitute actual emissions for pollutant control and/or retention measures. Given therefore the receptor and emitter uncertainty about what the technical marginal rate of substitution of air cleanliness for non-air inputs will be in t + n, views as to what these rates will be are likely to differ among individual receptors, among individual emitters, and between the group of receptors and the group of emitters. The perception from firm to firm of different marginal technical rates of substitution of the air input for non-air inputs implies that views of the firms about the price of the air input, as determined by receptor damage costs and emitter cost-savings, differ from one another. These differing views about the future price of the air input imply, in turn, differing views about the price of receptor goods relative to emitter goods. Given these differences in views, the aggregate production of emitter output and receptor output will, as is well known, fall below the production possibility or transformation frontier because the marginal technical rate of substitution between the air and non-air inputs for all emitter and receptor firms will not be equal to the marginal technical rate of transformation between emitter output and receptor output for all emitter and receptor firms.[23] The greater are the differences in views about future cost-savings and damage costs, the further will be the sum of emitter output and receptor output below the production possibility frontier. Conversely, any action which tends to reduce uncertainty about the level of pollutant fumigations and associated damage costs and cost-savings in t + n will increase the sum of receptor and emitter outputs.

One way of bringing about absolute receptor and emitter certainty with respect to the level of pollutant fumigations at some future date is to specify the maximum concentration of pollutant materials which will be allowed in the receiving medium as of that date. That is, the air pollution control authority specifies an ambient air standard. In Figure 18, receptor output, R, is measured on the horizontal axis and emitter output, T, is measured on the vertical axis.[24] The slope of

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[23] For the manner in which the production possibility frontier for receptor goods and emitter goods can be derived from knowledge of the substitution possibilities of non-air for air inputs, see F. M. Bator, "The Simple Analytics of Welfare Maximization," The American Economic Review, 47 (March 1957), pp. 23-26.

[24] It is assumed that both outputs are produced with short-run increasing unit costs and constant returns to scale.

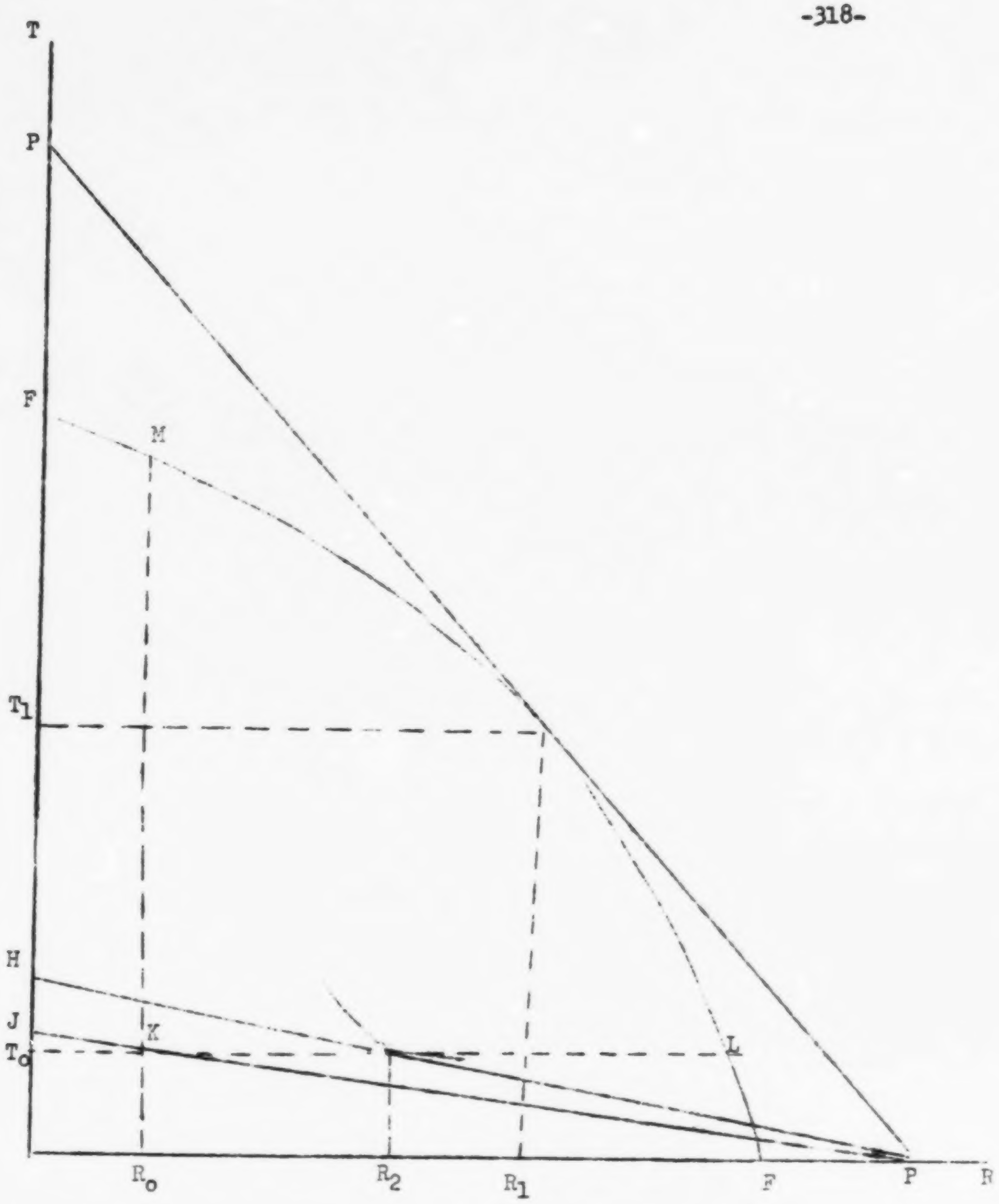
T
P
F
M
T_1
H
J
K
T_0
L
R_0
R_2
R_1
F
P
R

FIGURE 18

PRODUCTION POSSIBILITY FRONTIER FOR
RECEPTOR AND EMITTER OUTPUTS

the production possibility frontier, FF, shows the marginal rate of transformation between receptor output and emitter output, i.e., it shows the number of units of one output which under perfect certainty must be sacrificed in order to obtain an additional unit of the other output.

Assume that with receptor and emitter uncertainty about the level of pollutant fumigations in t + n, R_0 units of the receptor output are produced and T_0 units of the emitter output are produced. Now presume that the air pollution control authority promulgates an ambient air standard specifying the concentration of pollutant materials which must not be exceeded. The value of the emitter output relative to the value of the emitter output implied by this ambient air standard is assumed to be given by the slope of the price line PP. Having had the ambient air standard related to the price line PP established with certainty, the receptor will now produce at the output level R_1 and the emitter will produce at the output level T_1: the establishment of the ambient air standard has served to increase both parties' outputs.

There is, of course, no reason to suppose that the price ratio PP implied by the ambient air standard will necessarily conform either to the ratios in t + n of the market prices of emitter and receptor outputs or to the market prices of air and non-air inputs. There are, after all, influences other than only the amount of the air resource made available which will help to determine the prices of emitter and receptor inputs and outputs. When t + n arrives, demand conditions in the emitter output market may, for example, be such as to cause the collection of emitter firms to produce a quantity of output from whose production is generated a volume of emissions exceeding the ambient air standard. If incompatibility of this sort occurs, then the control authority can impose a tax (effluent charge) upon the emitter output or upon the pollutant emissions generated by the production of that output. In the case illustrated in Figure 18, the tax is assumed to be the dollar equivalent of PH along the vertical axis. After the imposition of the tax, R_2 units of the receptor output and T_o units of the emitter output are produced. The sum of receptor output and emitter output is higher with the ambient air standard than without it because, though no additional emitter output is being produced, some additional receptor output is being produced.

Of course not every ambient air standard with or without an effluent charge will serve to increase the sum of emitter and receptor outputs. Nevertheless, there are a large number which will increase this sum. In Figure 18, for example, with the ambient air standard associated with PP, an effluent charge greater than the dollar equivalent of the distance PJ along the vertical axis would cause a reduction in one group's output even if it did bring about an increase in the other group's output. However, given the initial level of uncertainty and given that it is unnecessary to impose an effluent charge making all combinations of receptor and emitter outputs within the KLM space unattainable, any ambient air standard implying an output price ratio and associated marginal rate of transformation between M and L will increase at least one group's output and will not reduce the output of the other group. The greater the extent of initial uncertainty about levels of future pollutant fumigations, the larger is the KLM space, and, therefore, the greater the number of ambient air standards serving to increase the sum of emitter and receptor outputs. And even when emitter output programs cause the pollutant concentrations established by the standard to be exceeded, the imposition of an effluent charge which causes the standard not to be exceeded will ensure that the emitters to whom the release of the marginal pollutant unit makes the greatest contribution will be those who are willing to pay for the right to release the marginal unit. That is, the right to release the marginal pollutant unit and each intramarginal unit will go to those emitters who would have to sacrifice the most if they didn't have available the right to release these units. In spite of the existence of the ambient air standard however, it is nevertheless entirely conceivable that within the constraint imposed by the standard individual receptor and emitter bargaining could still be carried on. However, since individual receptor and emitter bargaining can still affect other receptors and emitters--the existence of the ambient air standard has not altered the physically indivisible nature of the air resource--any economic gains achieved through such bargaining may be more than negated by losses due to an increase in uncertainty.

III. CONCLUSIONS

Among the main conclusions and comparisons of this and previous chapters are the following.

(1) "Clean" air, however reasonably defined, is a superior economic good.

(2) A greater tendency to arrive at voluntary agreements about methods of dealing with externalities is exhibited when a legal framework is established in which the burden of searching for agreement is placed upon the group whose members can most readily coordinate and/or least expensively implement their decisions. In short, agreement is

most likely to be reached when the burden of search is placed upon those best able to protect themselves.

(3) At least for the effects of fluorides upon beef cattle and citrus, most experimental work has been concerned more with finding good indicators of fluoride damages rather than determining the relationships between pollutant concentrations and yields.

(4) The use of experimental data from the natural sciences for the construction of receptor damage functions is highly questionable because of the scientific "need" for luxury provision of all non-experimental inputs.

(5) The use of only market data to determine receptor damage functions is justified only when the second derivative of the market nonparticipants' total damage function has the same sign and value as that for the market participants.

(6) Any attempt to specify damage cost and cost-savings functions must explicitly recognize the possibilities for temporal and physical input substitution and scale variations that emitters and receptors have open to them.

(7) Because political and juridical issues and configurations can effect the economic returns to be acquired from the air resource at least as much as purely economic phenomena, attention must be given to the bargaining possibilities available through them.

(8) Trade in negative externalities has occurred in the Polk County case.

(9) Trade in negative externalities did not take place in Polk County until revisions in operative emitter and receptor property rights made gains from trade desirable and visible.

(10) Those receptors who benefited from the Polk County situation were not always those who were initially harmed by fluoride pollutant fumigations but rather those who were best able to see the opportunities for trade in negative externalities presented by the policies of the Florida control authorities.

(11) Since cattlemen had more substitute inputs available than citrus grove owners and since they could adjust to variations in pollutant fumigations more rapidly, the policies followed by the Florida control authorities benefited the cattlemen relatively more than the citrus grove owners.

(12) One of the most striking features of any air pollution problem is the high level of emitter, receptor, and control authority uncertainty caused by costs of policing, acquisition of information, and coordination of decision-making.

(13) One of the major costs associated with emitter and receptor uncertainty about future levels of pollutant fumigations is the cost to emitters and receptors of maintaining input flexibility.

(14) To the extent that uncertainties create inefficiencies, any measure which provides greater predictability also promotes efficiencies.

(15) If damage cost functions and cost-savings functions are continuously and fully specified and if effluent charges by themselves are to be employed to control emissions, everybody else will be at least as well off and receptors will be better off with receptor compensation.

(16) If effluent charges are to be based on observed receptor damages, the use of receptor compensation can lead farther and farther from the quantity of emissions that would occur in a perfect market for emission rights. The result could be that the control authority's actions tend to maximize the damage costs prevented rather than minimize the sum of damage costs occurring and cost-savings foregone.

(17) Because of the high level of uncertainty associated with the sole use of the effluent charge as a control device, there appear to exist many ambient air standards which, when combined with emitter charges and receptor compensation, would improve existing conditions. The ambient air standard, at some cost in the fulfillment of the static optimality conditions, would provide a mutual compatibility of expectations between emitters and receptors.

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